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Maritime Interdiction Operations in Logistically Barren Environments

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Maritime Interdiction Operations in Logistically Barren Environments

by

SEA-13 Integrated Project Team

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This report was prepared by the students of Cohort 13 of the Systems Engineering Analysis (SEA) program as an integral part of their educational process and is a degree requirement for them. The SEA team was augmented by students from Singapore, under the auspices of the (Singapore) Temasek Defense Systems Institute (TDSI) as well as students from other curricula to permit the team to address the broad, interdisciplinary nature of the project. The team consisted of:

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13. ABSTRACT ***(Maximum 200 Words)***

This report contains analysis that shows that existing technology exists to improve Maritime Interdiction Operations (MIO) by approximately 30%. Furthermore, analysis contained herein will aid MIO planning for future operations. Since MIOs are an inherently dangerous, but necessary activity with far reaching implications to theater political and economic dynamics, this improvement is of great interest. MIO is a Naval solution to the problems of smuggling weapons, explosives, people and narcotics. MIO, when employed correctly has the potential to save lives and limit economic/political damage.

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ABSTRACT

This report contains analysis that shows that existing technology exists to improve Maritime Interdiction Operations (MIO) by approximately 30%. Furthermore, analysis contained herein will aid MIO planning for future operations. Since MIOs are an inherently dangerous, but necessary activity with far reaching implications to theater political and economic dynamics, this improvement is of great interest. MIO is a Naval solution to the problems of smuggling weapons, explosives, people and narcotics. MIO, when employed correctly has the potential to save lives and limit economic/political damage.

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EXECUTIVE SUMMARY

In situations where U.S. and Coalition forces are confronted with more potential targets to conduct Maritime Interdiction Operations on than can possibly be achieved, the success rate (and associated probabilities of making a find) is inherently linear. The amount of time spent onboard a vessel needed to achieve a given probability of detection against a specific type of cargo is the key metric for success.

Given that metric, research and analysis contained within (chapter 6) details how the amount of time spend onboard a target vessel can be significantly reduced and/or the probability of detection against specific cargoes (notable explosives, narcotics, and chemical weapons) can be greatly improved. Exploration was done to show how probability of detection against human trafficking can be done and is detailed in the same chapter.

A communications architecture is proposed that will allow seamless communications for the boarding team. Throughput requirements are detailed that will allow boarding teams to prosecute biometrics from a target ship as well as communicate with each other and the parent ship under channel conditions similar to what would be found on typical cargo vessels in chapter seven.

Contingencies (chapter four) and equipment that might be used for a response (chapter eight) is identified as well. This paper describes possible ways of dealing with an opposed boarding scenario without risking an untrained/uncertified boarding team or requiring special operations forces (SOF) support.

Throughout, very few assumptions are made regarding the logistics provided in theater. Analysis also explores the effects of reduced logistics on a MIO force under a variety of different scenarios (chapter nine). A cost estimation is provided in chapter ten.

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We would like to thank our families and friends for their tireless support of all of us that made up this great organization and fantastic report.

Lastly, this report is dedicated to all those who have or ever will don a flak jacket and do a MIO. It is our sincere hope that the contents of this report will have made your mission either safer or more effective.

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I. INTRODUCTION TO MARITIME INTERDICTION OPERATIONS (MIO)

A. DEFINITION OF MIO

1. NATO Definition

Although the phrase Maritime Interdiction Operations (MIO) may be largely of U.S. origin, the implementation of such actions is certainly not. The North Atlantic Treaty Organization (NATO) Allied Joint Publication 3.1 defines MIO as being principally composed of five distinct areas. Those areas are: Seaborne Enforcement, Interdiction of Enemy Forces, Interdiction of Commercial Shipping, Embargoes and Quarantine, and Blockades.[1]

a. Seaborne Enforcement

Seaborne enforcement refers to the use of naval forces to stop the movement of specific maritime supplies. In general, this is done as a measure to compel the targeted nation to take an action that said nation would not otherwise take under their own volition. In general, seaborne enforcement achieves this end by threatening the combat effectiveness of the target country's military. The target country's military is affected as the MIO would be limiting the influx of needed military supplies.

b. Interdiction of Enemy Forces

The same maritime forces can be applied directly against enemy warships and fit within the NATO definition for MIO. The purpose of such action is to prevent a potential adversary from utilizing the maritime domain for a purpose deemed undesirable by an internationally recognized authority. Use of

[1] AJP 3.1, 1-11.

naval forces to interdict an adversarial surface combatant constitutes an act of war.

c. Interdiction of Commercial Shipping

As with seaborne enforcement measures, interdiction of commercial shipping is intended to target an adversary's ability to wage an armed conflict of any form. An insurgency is an example of such an armed conflict. One example goal of a MIO campaign might be to limit the flow of supplies necessary to operate an insurgency.

d. Embargoes and Quarantines

In general, embargoes and quarantines associated with a United Nations Security Council Resolution target a specific country and specific set of cargo. This style of MIO campaign is also done to influence the behavior of a targeted country or organization.

e. Blockades

A total blockade is by definition an act of war. A blockade is intended to completely deny the use of the maritime environment to an adversary. Economic trading partners of the targeted country are also affected as it is a total stoppage of material supplies into and out of the waters of a country.

2. U.S. Joint Publication Definition

Compared to the NATO definition for MIO, the U.S. definition is a great deal broader. It states the following:

> Interdiction operations are actions to divert, disrupt, delay, or destroy an enemy's surface capabilities before they can be used effectively against friendly forces, or to otherwise achieve objectives. In support of law enforcement, interdiction includes activities conducted to divert, disrupt, delay, intercept, board,

detain, or destroy, as appropriate, vessels, vehicles, aircraft, people, and cargo.[2]

The use of the phrase “surface forces” implies that this definition is directly applicable to the definition of a MIO. The list of to divert, disrupt, delay, intercept, board, detain or destroy implies the start of a very high level view of the principal functions of a MIO. While the U.S. definition does not specify the reasoning for why a MIO would take place, it can be reasonably concluded that the intentions are very much the same as are defined in the NATO definition.

B. PURPOSE OF MIO

As a very strong generalization, the fundamental purpose of doing a MIO is to influence an event on land. MIOs are generally not done as a result of anything that is intrinsically maritime in character, but instead targeted against the second order effects of the movement of personnel and equipment through the maritime domain. While MIOs have been employed against hijacked passenger liners for the purposes of interdicting a team of pirates, the probabilities of such an occurrence are historically shown to be very rare, while the vast preponderance of MIOs are targeting cargo carries of one form or another. As it is the second order effects of the conduct of a MIO that stand the greatest chance of influencing world events, the optimal generation of these types of second order effects is the target purpose of this analysis.

MIOs are selective in nature. While a full blockade of a country or countries is included in the definition of a MIO, a MIO campaign must be able to selectively interdict only certain cargoes, while allowing non-targeted cargoes to pass. An implied goal of that task is to allow non-targeted cargoes to pass with minimal disruption or delay. Disruption and delay to legitimate commercial shipping is likely to incur adverse effects regarding the perception of coalition forces.

[2] Joint Publication 3-03, I-1.

MIOs are done for the purpose of constricting the flow of all or specific cargoes through the maritime domain in accordance with an internationally sanctioning body. Examples of MIOs throughout history include the blockade of oil out of Iraq from 1991-2003, attempting to stop the flow of elicit narcotics into the United States using the Coast Guard, and the coalition forces operating off the coast of Iraq from 2003 to the time of the writing of this report attempting to prevent insurgent materials from entering into Iraq.

The MIOs orchestrated by SOUTHCOM to interdict narcotic flow into the United States is done for the specific purpose of reducing the profit of the drug cartels, and to prevent narcotics from entering into the United States. In no case is a MIO purely a naval event. In all cases, MIO is done in support of a ground activity somewhere.

C. SCOPE OF ANALYSIS

1. Tasking Statement

The problem statement for SEA-13 to consider is as follows:

> Design a system of systems to employ a regional Maritime Interdiction Operation in a logistically barren environment.
>
> The system should be capable of collecting maritime intelligence and conducting rapid intercepts based on that intelligence to execute theater security, crisis response, and law enforcement missions in a coalition, interagency and joint environment.
>
> Consider current fleet structure and funded programs as the baseline system of systems to execute security and shaping missions in developing these concepts of operations, then develop alternative architectures for platforms, manning, command and control, communication, and operational procedures to evaluate against the current program.[3]

[3] SEA-13 Tasking letter, see Appendix A.

There are seven major terms identified in the above subject area that have reaching and definitive implications for the analysis in this paper. The full tasking letter is included in Appendix A.

2. System of Systems

A system is an interacting interdependent (or temporary) set of variables (exemplified as elements) that maintain certain relations (functions, behaviors, and performance) through time, where the present state of a given variable is dependent on its own past state as well as the other variables. The principle of "the whole is more than the sum of its parts" is implied by the systemic construction of system elements into a higher-order configuration of stability. Since the configuration is stable there are a number of emergent properties and constraints. Therefore a stable system can then again function as a building block, and combined with other building blocks form an assembly of an even higher order, in a recursive way. Stable assemblies will tend to contain a relatively small number of building blocks, since the larger a specific assembly, the less probable that it would arise through blind variation. This leads to a hierarchical architecture that can be represented by a "tree". As the building blocks are constructed and integrated within the system, a time results when the continuing dependence on overall operational, managerial, geographic, emergent behavior, and evolutionary development become less distinct and contrived. Thus when the system is comprised of large scale concurrent and distributed systems with independent operational and managerial stewardship it is necessarily better considered as a system of systems.

The requirement for this to be a system of systems to conduct maritime interdictions opens up some latitude with regards to the scope. Systems whose operational and managerial functions are controlled outside of the MIO system but which could otherwise be in the general vicinity of the operating environment may be considered in the analysis. In order to be able to function inside of a logistically barren environment, the logistics system of U.S. TRANSCOM is required. The exact requirements and measures of effectiveness and performance for this system are detailed in chapter nine. Also, some degree of overhead ISR may be available. These systems are not described in detail, but their implications are closely studied in the both chapters four and eleven.

3. MIO

The extent of MIOs being studied in this document is less than the total breadth of MIO as defined by the NATO definition above. In this particular case, full blockades are of little interest. Such events are acts of war that are done with a multitude of warships. Since the intent of the blockade is the forced total cessation of the targeted country's use of the maritime environment, rules of engagement allow the employment of significantly greater destructive measures. The ability of the U.S. Navy to sink ships is not the intent of this study as it is believed by the authors that this capability is already refined to an adequate degree.

The interdiction of enemy surface forces is also not considered in this study. Such events are either in the realm of general naval surface warfare (i.e. sinking enemy combatants), or very unlikely (i.e. utilization of Special Operating Forces to capture enemy surface combatants). In either case, interdiction of enemy surface forces is not considered in this paper.

Embargoes against generic goods are not specifically addressed in this document. Although the ability to stop ships and search them will be discussed at great length here, targeting a generic cargo is not considered.

The remaining three areas of the NATO definition of MIO are the principal subject of this document. Targeted cargoes are limited to smuggled humans/animals, illicit narcotics, and conventional weapons in the forms of guns, mortars and explosives.

4. Logistically Barren Environment (LBE)

a. General LBE Constraints

As "barren" is the operative word, it is important to carefully define what this means. Taken straight from the Merriam-Webster dictionary, barren simply means "devoid, lacking." As barren is an adjective and it is implied to the environment, then it can be taken to mean that the environment (for which the MIO system of systems will be operating) is devoid or lacking of something. Since the environment is defined to be logistically barren, then one can conclude that the environment is lacking or devoid of all logistic support necessary for the MIO system of systems.

As a consequence of operating in a logistically barren environment (LBE), it becomes necessary to identify any constraints imposed as a result of a lack of logistic support. Some assets can be considered universally available. As an example, the Inmarsat communication system is available everywhere on Earth where a geostationary satellite can be seen from the ground. As this encompasses one-third of the Earth's surface per satellite, and there are only four Iridium satellites, it can be reasonably assumed that Inmarsat communications services are available everywhere that MIOs will be performed. Geostationary satellites cannot cover the polar regions of the planet, but this only presents a problem in the Arctic Ocean. As it is assumed the majority of "hot-spots" in the world will be in the equatorial band, it is assumed that existing geo-stationary satellite capacity will be available for use as part of the system of systems. Further analysis will be careful to delineate when this assumption is used. By the same logic, satellites in low Earth Orbit (LEO) are assumed to be available for the period of time consistent with the overall footprint of a given satellite constellation (i.e. Iridium).

Perfect logistics cannot be assumed in real life, and are not assumed in this report. It is however assumed that any given part that is ordered by an operating task force will eventually arrive, though the time of arrival cannot be guaranteed. As such, the definition of a logistically barren environment is expanded to state that if the time of arrival of a part or system is strongly guaranteed, then the environment is not logistically barren.

For example, operating off the coast of California is not logistically barren, as a well established shipping system within the Continental United States (CONUS) does a generally superb job of getting things where they need to go. If ISR assets are requested off of the coast of CONUS, then there are a multitude of US military bases that can supply such a force. However, when operating off the coast of a country whose participation and/or support for a given operation is potentially more limited, then the time of arrival of a coalition asset cannot be guaranteed. The current supply system used by US and coalition militaries does a good job in delivering parts and supplies to its consumers, but makes few guarantees about when any particular part will arrive.

High value assets like Navy SEALs are considered scoped out of this problem. While their presence would be immensely valuable in a number of situations presented in this report, it cannot be guaranteed that such special operations forces (SOF) would be present at the outset of a crisis. Since a crisis would be intensely time dependent, and the time of arrival of a SEAL team is not considered a guarantee (at least, not as reliable as supply delivery in CONUS), situations that would ordinarily be handled by SOF forces must have alternative solutions developed for them.

Part of the system of systems architecture includes a logistics/transport system. This system will have to be capable of bringing in materials (critically needed spare parts, food, fuel, etc) needed for continued operations of any kind. As this system will be bringing things into the environment, it is immune to the constraints of a logistically barren environment.

b. Weapons of Mass Destruction (WMD)

In the event a WMD is smuggled on board a ship targeted towards CONUS or any other city, all the implements of national power by all nations will be available for use in locating the carrying ship. It could be reasonably argued that there are not enough naval forces to find an atomic bomb loaded on an arbitrary ship somewhere in the world. However, this paper makes no effort to solve that problem.

If one were to attempt to develop a solution to such a problem, then one would start by removing any and all logistically barren constraints and assume the absolute and enthusiastic support of every nation on the planet. Since the idea of developing a MIO system that is designed to operate in logistically barren environments (as defined earlier) runs directly counter to the best starting location for solving the problem of WMD onboard ships, this problem is scoped out of the analysis.

5. Collecting Maritime Intelligence

The main purpose for this project is to study MIOs, as opposed to devising different means of collecting maritime intelligence. Collecting maritime intelligence is considered here, but is mostly limited to how it relates towards doing better MIOs and the collection of intelligence during a MIO.

The problem of how to find a given ship at sea is considered here, and two fundamentally different means of solving this “macroscopic intelligence” problem will be addressed in chapter 7 of this report. Studying the problem of how to locate contacts at sea or conduct large area ISR is not a new problem to the Navies of the world. This problem is considered the “macroscopic intelligence problem” and will be given a due consideration in this analysis.

The intelligence needed to determine which ship to board next is not going to be easily gleaned from a macroscopic intelligence picture. It is assumed in this report that the actual intelligence necessary to determine which ship to board next will be obtained via exploitation of material and people found onboard targeted ships. Intelligence collected from previously boarded ships by the MIO task force is also used. Furthermore, access to national databases is assumed (as they are as ubiquitous as the global information grid) to further assist in the processing of intelligence gathered from the conduct of MIOs. The problem of how to collect intelligence gathered during a MIO is referred to as the "microscopic intelligence problem" and is the subject of primary consideration in this report.

Both macroscopic and microscopic intelligence problems are considered here, with due deference given to the latter rather than the former.

6. Conducting Rapid Intercepts

"Rapid" is considered to imply speeds on the scale of common manned and unmanned aircraft. Paired with the word "intercept" and in the context of this problem statement, this suggests that the designed system of systems must be able to move at a "rapid" speed to be able to stop a designated target within the designated LBE.

7. Execute Theater Security, Crisis Response, and Law Enforcement Missions

This implies that a certain minimum degree of force must be organic to the system of systems. That minimum degree of force needs to be sufficient to be able to influence the decisions of countries within the region. Assumed examples of crisis that the system of systems would need to respond to include the Indonesian tsunami of 2004, the mudslide of Leyte Gulf in 2006 or the tropical cyclone that struck Myanmar in 2008. With regards to law enforcement missions, the MIO teams must be able to collect evidence (as well as intelligence), and must be able to exert ample force to selectively arrest, detain or kill specific individuals as situations and rules of engagement require.

8. …coalition, interagency and joint environment

There are three principal implications to this statement:

a. Communications Standards

Especially in the case of coalition inter-operability, it cannot be assumed that all participating coalition countries would have purchased compatible communications equipment. For the purposes of this analysis, US ships will have a communications capability comparable to present day technology, and communications needs and standards for coalition ships will be defined. In some cases, designated "fly-away" equipment to loan to coalition ships will be identified in this analysis.

b. Legal Issues

While the US is not a signatory to the United Nations Convention on the Law of the Sea (UNCLOS), the preponderance of nations are signatories. While the U.S. Senate had not yet ratified the treaty at the time of the writing of this report, the US conduct of operations has always been in concert with the spirit of the UNCLOS. The United States President George W. Bush has also sent the UNCLOS treaty to the U.S. Senate where it awaits ratification. As this is assumed to be a coalition environment, restrictions of this convention and where applicable, recommendations for changes will be introduced.

c. Intelligence vs. Evidence

Intelligence collected for the purposes of combating an adversarial entity need not necessarily always adhere to the rules of evidence necessary to convict an individual in a court of law. The standard for documentation and collection of evidence is significantly higher for evidence than intelligence. As one of the primary targets for a MIO is an insurgency, and the establishment and authority of a working legal system is key to the success of a counter-insurgency operation, this report will target intelligence collection to the standard of "evidence collection" whenever possible. If there is a discrepancy in capability limiting collection to only "intelligence", the difference will be identified for the reader.

Additionally, as the problem statement requires an inter-agency environment, some federal agencies potentially cannot utilize intelligence information to accomplish their functions. Information about the guilt of an individual that is garnered through less than legal means (intelligence) is often not admissible in courts of law. Collection of "evidence" that can be freely shared with law-enforcement agencies would be a key tenant to the successful employment in the real world of such a system of systems.

9. … security and shaping missions …

As stated earlier, the ability to perform security and shaping missions implies a minimal amount of force. MIO is inherently a subset of security and shaping operations. Security and shaping operations can also include everything from a psychological operations broadcast to presence/deterrence operations. In chapter 2, the implications of a minimal force necessary to perform these missions as it relates to the chosen architecture is examined.

10. Timeframe: 2013-2014

While the problem statement does not specifically identify a timeframe for the problem, it does indicate that "current systems" will be used as a baseline. Since the current (2008) baseline is considered the starting point, it is assumed that the framers of the question are interested in how best to allocate request funds for the next Program Objective Memorandum (POM) cycle. It is also assumed that in the event that congressional funding was needed to procure any large systems of high value in this system of systems, approximately five years would be needed. As a result, the timeframe of 2013-2014 was selected.

If an earlier timeframe were chosen, then the selection of systems that could be procured designed or developed would be more limited. Additionally, the analysis would be targeted towards a year inside of the existing POM cycle as of the writing of this report. Had the timeframe been later, then the accuracy and immediate utility of this analysis would be degraded as the probability for technology to have taken a greater advance (or failed to make an anticipated advance) would have been greater.

11. Location

The problem statement did not deliberately specify any particular region of the world. As a result, several assumptions are made in order to scope the analysis of this project.

a. Hotspots

It is assumed that the place for which the system of systems will be operating is a political "hotspot" in that there is some form of political strife, insurgency, separatist movement or a rogue nation operating at the start of the problem. This implies that the location will be someplace where there are people present and someplace in the world that is politically unstable in 2008, while also having the potential for instability in the years between 2013 and 2014.

b. Globally Applicable

In later analysis, a specific region of the world will be defined as a scenario for the employment of the system of systems for MIO. The location defined is a generic location. There is nothing in the analysis that limits the applicability of the designed system of systems to just that specific area of the world. The finished product described here will be intended to be globally applicable to all areas of the world where MIOs would be done.

12. Level of Force

The purpose of this paper is not to define the rules of engagement necessary to accomplish a specific mission in a specific scenario. Rules of engagement will generally be very permissive and be limited to not harming innocents or friendly units. Disabling fire will be allowed. None of the scenarios used here will require employment of destructive fire capabilities.

13. Level of Boarding

All levels of boarding, as defined by NTTP 3-07, will be considered in this analysis. Whereas the typical response to an opposed boarding given the 2008 baseline would be to request SOF support, it is assumed for this analysis that SOF will be unavailable and alternative methodologies for coercing the ship to be cooperative in the boarding will be employed. Such strategies are developed in this report.

D. FUNCTIONS IN A MIO

There are eleven different major functional areas within the construct of a MIO. They and the reasoning behind them are as follows:

1. To Provide Logistic Support

The need for a logistics functional area is abundantly clear from the problem statement. The problem is set in an LBE. Given the previous definition of LBE, it becomes readily apparent that in order for this system of systems to be functional, a logistics tail will be necessary. The details of the logistics tail necessary to support this system of systems are detailed in chapter ten.

2. To Provide Information Superiority

There are two fundamental parts to providing for information superiority. The complete analysis of this function is included in chapter seven.

a. To Collect Intelligence

The first part is the collection of intelligence. In the case of this analysis, the collection of intelligence is centered on the maritime environment with the greater emphasis on the microscopic piece. The need to collect maritime intelligence is specified by the problem. Additionally, macroscopic intelligence provides very little information with regards to determining whether or not a particular target vessel is smuggling elicit cargo. As will be shown in this analysis, obtaining a priori knowledge of which contacts are smuggling elicit cargo greatly increases the effectiveness of the MIO. This a priori knowledge cannot be obtained via macroscopic means within the confines of a logistically barren environment.

b. To Communicate

The second fundamental part of providing information superiority relates to the communication linkages between friendly units and intelligence gatherers. Information available in a national database needs to be accessible (and updated by) intelligence collectors operating in the LBE. Tactical events that occur need to be communicated to the units conducting MIOs as they occur. Maintaining the links of communication to allow the system of systems to function in its capacity of doing MIO is an essential function.

3. Operations Management

As with any complex system of interoperating parts performing multiple simultaneous functions, there is a management function required. This function will include things such as asset management, asset planning, contingencies development and ISR management.

4. Maneuver

Actually making a transit in between an origin or set of initial conditions to a point where the MIO will be conducted requires that participating ships and aircraft actually make the transit. As such, “maneuver” is a key functional area with regards to MIO.

5. Detain

The potential exists that a vessel targeted for MIO would not be allowed to enter a port facility, a country's territorial waters or to be allowed to escape from the vessels implementing the MIO. As such, a function of the system of systems to do MIO must be able to detain a vessel against that vessel's will.

6. Disable

If a vessel is deemed of such quality and a substantial enough threat it may become necessary to render the vessel into such a state that it is no longer capable of continued transit under its own power.

7. Board

For some senses of the definition of MIO, boarding is not required in order to interdict, as would be the case for a blockade. However, if the target of a MIO were a specific cargo onboard the ship, then it becomes a requirement to get personnel onboard the target vessel in order to conduct such a search. While the nature of the boarding may vary depending on the behavior of the target ship's crew, the simple function of being able to place personnel on the target ship is required, in order to ensure successful interdiction when dealing with specific cargoes.

8. Recover

If personnel are going to be placed onboard a targeted vessel, then there will be a requirement to remove these personnel at some point. It is important to consider the situation where one boarding team member is leaving at a time. This single threaded system would leave the last member of the boarding team in a vulnerable position relative to the rest of the crew, and is considered in detail in the boarding/recovery chapter.

9. Search

In between the boarding team's arrival and departure at the target vessel, there will be a requirement for them to search the ship for the elicit cargoes described in the scoping section of this report. It is likely that these cargoes will be hidden onboard the targeted vessel.

10. Abort

To be able to abort from a MIO is a function the system has to undertake. Depending on the time that the decision to abort takes place, the implications change. For instance, if the MIO is aborted just prior to the boarding team launching, then there are fewer implications.

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II. SYSTEMS ENGINEERING OF A MIO

A. SYSTEMS ENGINEERING MANAGAMENT PLAN (SEMP)

1. Purpose

The purpose of including the SEMP in this report is to show interested readers the methodology for managing the process that led to the results detailed further in this report. A fully disclosed methodology will help the reader to determine the credibility of claims later asserted in this report.

The purpose of the SEMP is to show the methodology for managing the process that will lead to a project completed on schedule, on budget for all deliverables (as was the case for this project). SEMPs supplement the details of the Project Plan (as required); provide particular focus on the technical plan of the project and the systems engineering processes to be used for the project; detail the engineering tasks; determine the technical challenges associated with the project; determine the risks associated with the tasks; determine the extent of stakeholder involvement and influence on the project work; describe the processes needed for requirement analysis; describe the design and architecture analysis and analysis of alternatives; identify the resources available for the completion of the project; outline the project organization, schedule, and resource commitments; and detail the communications, roles, and responsibilities, of project team members.

2. Project Objective

The primary objective of this project is to design a system of systems that does MIOs. This is assumed to be the primary focus of SEA-13 as it is the first and most salient sentence in the project description. As the designed system of systems is to be evaluated against the baseline, the implication is that the framers of the original question were looking for improvements to the current baseline. New systems can also be evaluated against the current baseline. However, given the 2013-2014 timeframe requirement, development of new systems is avoided in this analysis. As such, beginning with the baseline and analyzing the various costs and benefits of different improvements are the means by which the primary objective will be accomplished. All improvements identified in this report are believed to be either available at the time of its writing, or by 2013-2014.

Where an adequate improvement cannot be made, the area of technology that would need investment in order to grow will be identified as a secondary objective.

Lastly, an evaluation of different architectures will be considered. Systems architecture is the fundamental organization of the physical, informational, and logical entities of the elements that comprise the system. The relationships between the elements and entities, the arrangement of said elements and entities, and the associated rationales form a descriptive set of perspectives (or views) that characterize the system operations and effectiveness.

All MIO improvements and alternative architectures identified are done under the scoping guidelines considered in chapter one. Key scoping guidelines are as follows:

a. Must be a System of Systems

The final system will be a combination of interoperable systems. The systems contained within the finished product should not be centrally controlled, but be capable of having governance of the system changed when needed.

b. A MIO Must be Performed

The completed system of systems must be able to conduct Maritime Interdictions (boardings), as well as be able to search a ship for contraband. The system of systems should be able to intercept moving cargo at sea, with or without the consent of the target ship crew.

c. Logistically Barren

The rules set forth in chapter one must be adhered to with regards to the logistics, employment or operation of any given system.

d. Target Sets

Target sets are limited to guns, mortars, explosives, humans and animals, as well as narcotics. Weapons of mass destruction (WMD) are explicitly scoped out.

e. Maritime Intelligence Collection

The finished system of systems must be able to collect intelligence across all scales.

f. Minimum Force Requirements

The requirements that a system is able to execute theater security, crisis response and law enforcement missions implies a minimum amount of force that the finished system of systems ought to be able to muster. The requirement for the finished system of systems to be able to handle shaping and security missions reinforces the minimal force ideal.

g. Timeframe (2013-2014)

The reasoning for this timeline is described in chapter one.

3. Organization/Team-Structure

The original functional decomposition (FD) of “to do a MIO” comprised of eleven functional areas. Since the span of control for an average leader is five to seven people, it was highly desired to have no more than seven groups. Composition of each team was intended to be mostly homogenous with respect to the degree field of study of each area in order to facilitate the ease of scheduling a meeting. However, it was also desired to have personnel who were well versed in system engineering processes in each team in order to help instill and reinforce the systems engineering process.

Team goals were focused on engineering the requirements to satisfy their respective pieces of the FD. Wide latitude was given to each group in order to best ensure an optimal solution.

a. Initial Organization

Immediately following the assignment of the tasking, SEA-13 was split into four different groups. One group was focused on analyzing all available open source information with regards to the tactics, techniques and procedures for MIOs as done by various countries around the world. Another group was focused on analyzing the technologies employed for MIO for those countries. A third group was focused on examining the works of past SEA projects. A final group was the Executive Steering Group, whose focus was to design the way ahead following the completion of the work of the first three groups. All four of the initial groups completed their tasking according to the plan and schedule.

b. Group Assignments

Individuals were assigned to groups based on three different criteria: 1) volunteerism, 2) curriculum and 3) country of citizenship. It was desired to make each of the teams as diverse as possible by way of nationality in order to ensure that the views and values of represented cultures were included in the final product. Since the team functions closely mirrored some of the available curricula, it was desired to make each team homogenous with this respect. As an example, the operations group was made almost entirely of operations research personnel. All of the electrical engineering and information assurance personnel were assigned to the information superiority group. The students from the systems engineering curriculum were assigned across most of the teams, which prevented groups from being completely homogenous.

Individuals volunteering to be on a specific team were often given leadership positions. In determining team leadership structure, volunteerism, enthusiasm, communication skill and willingness to debate (as a positive quality) were the primary factors considered. Seniority was not a consideration. Volunteerism was the primary consideration.

The number of groups was calculated based on the idealized assumption that no one person should have a span of control exceeding seven people. With forty-six personnel assigned to this project, seven teams of five to seven people generated the ideal teams for each functional area. With eleven different functional areas identified, this meant that each team took cognizance over one to two different areas. Other areas of the functional decomposition (such as 'legal' or 'abort') are considered by each of the teams themselves and were not placed under the cognizance of any one particular group. Table 1 details the mapping between major functional areas and group designations.

In addition to the groups identified (by functions of a MIO) in Table 1, there was a separate group responsible for modeling and simulation that contributed to all MIO functional groups. This group was composed primarily of personnel from systems engineering, operations analysis and the "modeling, virtual environments and simulation" (MOVES) curriculum.

Functional Areas	Group Name	Primary Curriculum
Logistics	Logistics	Systems Engineering
Information Superiority	Information Superiority	Electrical Engineering, Information Assurance
Operations Management	Operations Management	Operations Analysis
Maneuver	Maneuver/Detain/Disable	Physics, Mechanical Engineering
Detain	Maneuver/Detain /Disable	Physics, Mechanical Engineering
Disable	Maneuver/Detain /Disable	Physics, Mechanical Engineering
Board	Board & Recover	Systems Engineering, Physics, Mechanical Engineering
Recover	Board & Recover	Systems Engineering, Physics, Mechanical Engineering
Search	Search	Systems Engineering, Physics
Legal	all	None
Abort	all	None

Table 1: Functional decomposition and respective group assignments

c. Group Communications

Group leads met once per week at a time at which everyone's schedules permitted. A single required meeting once per week of group leads, followed by regular email and phone contact between group leads and the project lead were the principal mechanisms for working through the project. At no point did it become necessary for SEA-13 to require specific work hours of all of their members. There was a multitude of lateral communications between groups that are detailed here. Major inter-group communication threads are detailed below.

Each student group met with their respective faculty advisor at least once a week.

CONOPS: The first piece of communication between groups was the development of a MIO Concept of Operations (CONOPS). The CONOPS document gave a realistic scenario, complete with campaign phases, which roughly approximated the kind of orders that a real world strike group might receive. The CONOPS document provided a baseline starting point for which each of the other groups could begin working on engineering and analyzing refinements to each of their respective areas.

Force list: The forces employed in the CONOPS were a key point which the logistics group began to consider. Since the intent of the logistics group was to calculate the logistics tail necessary to support the employment of a MIO package, this was a key point needed for that group to begin work.

Search space/time parameters: As a result of the early exploratory analysis done at the beginning of the project, it was quickly determined that the baseline for searching a ship was the manpower intensive employment of sailors that inspect ships using no sensor except the naked eye, aided only by a flashlight. It has since been shown to be beneficial to make a significant improvement on this search approach. It was determined that some form of technology could be added to aid in the searching process. Determining the implications of such additions with regards to the speed with which a sailor could search a compartment with a given probability of detection was the reason for constructing a model representing the sailors searching a ship, which is detailed in chapter eleven. The relationship between the size of a vessel, the capability to generate a probability of detection, the number of personnel operating sensor equipment and the available amount of time was a key parameter in developing both the search model, and was also a parameter for the larger Naval Simulation System (NSS) model[4] described in chapter eleven.

Specific equipment: Four of the seven teams in SEA-13 identified specific equipment that would be of value in conducting a better boarding operation. All recommended equipment is presented in this report for consideration. The potential exists for a given piece of equipment to require logistic support. The logistics team was the principal recipient of information from four other teams (boarding/recovery, info superiority, search and intercept/detain/destroy) in order to ensure logistical support.

Equipment mass/density: An objective of this report is also to identify the most effective mix of equipment for a team of a given size that is

4 NSS is a modeling system developed by Lockheed Martin for showing a macroscopic view of Naval combat. See chapter eleven for details.

looking for an illicit cargo of a given type. This equipment list has to take into account that all members of the boarding team must remain buoyant at all times, be able to climb a ladder for a given duration, and be able to effectively maneuver and fight while loaded. The boarding/recovery and search teams collaborated to ensure that these requirements were met.

Unmanned vehicle specifications: One area being modeled in the "NSS simulation" (described in chapter eleven) was the modeling of the effect on MIO if the quantity and quality of aircraft launched from the MIO platform were changed. For instance, if a typical destroyer that deploys with two SH-60Bs on board, then determining the full impact of replacing one of the SH-60Bs with multiple smaller unmanned vehicles that have greater range, search, and endurance was done.

Modeling design: There were a number of models built for this project whose size and complexity varied from simple queuing theory models up to elaborately complicated tactical simulations. The modeling team was largely responsible for providing much of the manpower and expertise for the construction of these models. Measures of effectiveness and performance, and parameters were produced as a product of the engineering and analysis done by each of the respective teams. The three principal models utilized in this project are the over-arching NSS model (described in chapter eleven), the search model, the boarding/combat model and various other analytic models.

d. External Communications

Prior to the final presentation of the engineering/analysis done in this report, there were two mid-course reviews of the material. Staff and faculty of the Naval Postgraduate School were in attendance and commented on the progress and development of the final product. The first mid-course review was held twice (7 Feb and 8 Feb). The second mid-course review was held on 10 April.

4. Systems Engineering Process

The systems engineering process employed was the domain process model (DPM). The DPM is formulated for problem solving, but in its abstraction, focuses on prototyping trade studies to reach ahead to solutions that then become the drivers for more detailed analyses. Areas of interest within a study are modularized into unique domains. For instance, architectural analysis was a domain unto itself and the various functional areas were considered in greater

The ultimate application of the DPM is to derive modules of functionality (activities and processes) that are independent of each other. A module implements an indivisible function, having only one input and one output. Independence means that the function of the module is unaffected by the source of the input, the destination of its output, and the history of the module. Modules must be separately testable and have uniform work content. Such refinements are the signs of a robust process and design. The application of DPM to SEA-13 implies that modules of work should offer flexibility in changing the aggregate unit to improve performance (and therefore quality). This flexibility is enhanced by dividing the tasks up into major functionalities. The result is a change made to one module should have only local effects for each change to that module of work.

As a result of the application of the DPM to SEA-13, the only major variable to change with regards to architectural analysis was the delivery platform. Changing of the fundamental methods for accomplishing each of the functional areas (or domains) of SEA-13 was accomplished within each chapter of this report.

A complete description of the DPM can be found in Appendix B.

5. Management Plan

a. Basic Strategy

In a typical SEA project, a purpose of modeling and simulation is to determine the relative value and cost of a given architecture. Here, modeling and simulation provide a more detailed refinement of the selected architecture.

Each of the teams (excluding logistics) employed a top-down approach to their respective functional area of MIO. Each group documented in this report their methodology and thought process that led them to a particular conclusion regarding a particular refinement. After the completion of the analysis/engineering that led to a given refinement, either a trade study or a model was developed to show the relative merit of a given architecture.

The nature of a MIO causes some activities to occur independently of other activities, so a monolithic single model of all MIO related activities was not considered. For instance, a boarding team will take some amount of time to secure a targeted ship. The amount of time that it takes a boarding team to secure a ship is a relevant input into the NSS model (as is described in chapter eleven) that shows the macroscopic movement of MIO related assets, neutral ships and target ships. However, the NSS model does not need to model the boarding team's movements inside of the target vessel; it only needs to know how much time would be lost as this activity occurred and what the associated probabilities that more time would be lost as a result of an injury, fatality or finding.

b. Constraints

No other guidance beyond the project statement was provided to SEA-13. With forty-six members, an implied constraint was that the project should be scoped such that the end product is reflective of their individual and collective intellect.

6. End-Product Requirements

The primary goal of this project is the generation of this report and the final stand-up presentation. The report's chapters and appendices will document the complete methodology, engineering and analysis done to generate the ideal system of systems to conduct maritime interdiction operations in a logistically barren environment. The presentation will provide a summary of the report, highlighting specifics that are of interest and representative of the breadth and depth of the report.

7. Risk management

Risks to schedule, performance, and quality were identified and managed. The major risks to consider with regards to completing the project and the mitigating steps are detailed below.

a. International Students Overloaded

Risk: SEA-13 was done with a majority of students arriving from Singapore. The project began simultaneously with their start of classes within a week of their arrival at NPS. Each of the Singaporean students was required to take four to five classes in addition to being tasked with making a relevant contribution to the SEA-13 overall outcome.

Likelihood: Absolutely certain

Consequence: Severe. The impact of this course load on two-thirds of the project team reduced the overall effectiveness of the team resulting in seemingly more ground covered with less detail. Therefore the majority of students working on SEA-13 were already overloaded. The Singaporeans and other international student members of SEA-13 made great contributions to the generation of this document; however it was done at great personal expense on their part, perhaps to the detriment of participating in the full learning experience offered by their other graduate-level courses. The U.S. team members for the most part have this project assigned during their last two quarters before graduation.

Mitigation: Ensuring a heterogeneous mix of U.S. team members in the project groups. This would allow a “lightly loaded” US student to pick up the load should any of the Singaporeans become overloaded. Also, ensuring that all students are enrolled in a class with a time slot associated with it. This would guarantee that teams would be able to meet on a regular basis.

b. Potential Lack of Proper Skill Sets

Risk: Students assigned to SEA-13 might lack the proper skill set necessary to conduct an analysis of a functional area. For instance, none of the SEA-13 students knew how to run NSS (see modeling chapter) at the start of this project. Although a student might be from a given degree field, that did not guarantee that the student has had all of the courses necessary nor had been exposed to all the relevant tools to function as an analyst in that field.

Likelihood: Moderate. All of the systems engineering curriculum personnel were in the last quarter at the start of this project. The majority of the membership of SEA-13 was well along their way. Very few were missing the requisite course loadings.

Consequence: Moderate, the greatest fear in this problem was that “you don’t know, what you don’t know”. If a problem was unknown, or a flawed methodology employed, the experience of SEA-13 members may have been inadequate to identify the flaw. At best, a resultant time delay could occur as extra time was taken to discover and correct mistakes.

Mitigation: The ambitious and early start SEA-13 had allowed for a greater deal of observer insight into the methodologies presented. Some of the final results were presented as early as the second IPR. Additionally, faculty involvement in interpretation of the results was essential.

c. Naval Simulation System

Risk: The NSS system was developed by Lockheed Martin for use by the U.S. Government to facilitate exactly the kind of analysis done herein. However, the product is relatively new. In early examination, NSS demonstrated very distinct instability problems. Furthermore, not all of the features inside of NSS worked correctly or as “advertised”. This required the modeling and simulation team to develop more creative solutions to implement the model.

Likelihood: Certain.

Consequence: Severe. Failure to run the NSS model would result in no information regarding the value of surveillance assets, helicopters or varied force packages. The queuing theory model would not be validated, and the amount of analysis that could be generated by SEA-13 would be severely limited.

Mitigation: For the first portion of the project, concurrent development of an NSS counterpart model was done in MANA. Though this model was a great deal more cumbersome than NSS with regards to workarounds, it might have been able to produce a result if the majority of SEA-13 personnel were assigned to work on it at the last minute. Furthermore, close and frequent involvement by Lockheed Martin personnel for training and technical assistance in configuration and operation of NSS helped to allow the product to run successfully.

8. Configuration Management

Configuration management of the document form of the final product was done using Microsoft’s SharePoint application. The interim process reviews were managed by emailing segments of the PowerPoint to the team lead’s email account and manually tracking/consolidating the slides.

With regards to computer models developed to answer specific questions about the MIO process, each individual group was responsible for management of these individual models.

9. Verification and Validation plan

Verification of the results was done primarily by peer review, comparison of results from different models and briefing the NPS faculty.

10. Product and Process Reviews

Two process reviews were done with open invitations to the staff and faculty of the Naval Postgraduate School. Soft copies of each of the two briefs were made available to outside entities such as OPNAV N86 and the CNO's Strategic Studies Group.

11. Description of Deliverables

The principal deliverable generated by this effort was a document that describes in detail the analysis and engineering work carried out. It was made sufficient enough in depth to allow a reader, who does not have an engineering degree to be able to formulate an opinion about the validity of the analysis conducted and to gain an appreciation of the results. In the case where modeling and simulation was done (or any physical experiments), enough information was given to allow follow-on researchers to be able to replicate the team's work.

12. Waivers

Classification levels were an issue. This analysis could have been conducted inside a Coalition Enterprise Information Exchange System (CENTRIXS) or an ad hoc enclave that had been properly accredited to the requisite degree of classification for the nationalities of all involved personnel. This would have allowed a much greater analysis to be conducted.

B. SYSTEMS ENGINEERING PROCESS

1. Needs Analysis

As with any systems engineering process, the beginning rests with the real reason that this work was being considered. MIO was being considered as there continues to be a legitimate deficiency in this area in the fleet at present day.

MIO is a supporting mission. Whereas an activity like surface unit warfare might be done for the specific case of destroying enemy naval combatants, MIO is only done in support of a larger objective. MIOs could be done in order to influence the political will of a government. They could be done to strangle the supply lines of an insurgency. For the purposes of this analysis, strangulation of the sea lines of supply utilized by insurgents was the principal target. The ability to cut off an insurgent group's use of the maritime environment for shipment of supplies allows the Navy to play a very significant role in future counter insurgency operations.

From 1990-2003, coalition Naval forces essentially blockaded Saddam Hussein's Iraq for the purpose of preventing his oil from reaching the open market in accordance with UN Security Council Resolutions. During this timeframe, MIOs were employed against the Iraqis to interdict this cargo. As stated earlier, the MIO was not done for the sake of itself, but rather to influence the Hussein government in Iraq.

From 2003 to the writing of this report, coalition forces employed MIO in the Northern end of the Arabian Gulf, and off the Horn of Africa in order to interdict the maritime movement of insurgents and insurgent supplies. Again, MIO was not done for its own sake, but rather to aide coalition forces ashore in their counter-insurgency efforts.

Some of the cargoes targeted in this document continue to be of significant value to terrorist organizations. Thus, it was reasonable to assume that they will take measures to either hide or defend their cargo. This implied that the safety of the boarding teams may very quickly become jeopardized should the crew of a targeted vessel choose to fight the boarding team rather than risk being captured. Therefore, there was a very strong need to ensure the safety of boarding team members. Should the need arise to place boarding team members in harms way, then there will be an obvious need to ensure that the boarding team has the best possible probability of survival and success.

Although the Arabian Gulf region provided a fertile base for which to derive plausible scenarios, analysis was intended to be generic to anywhere in the world. Concepts developed in this report were applicable to any maritime region.

2. Stakeholder Analysis

The process of a stakeholder analysis started with looking at all of the different items of value associated with a MIO from their initial assembly, to their disposal. Entities involved with the creation, movement or disposal of an item of value were considered stakeholders.

As stated in the scoping section of Chapter One, targeted cargoes were limited to smuggled humans/animals, illicit narcotics and conventional weapons in the forms of guns, mortars and explosives.

a. Originators

Narcotics: In South America, the cartels continue to be the most obvious generators of narcotics. In evaluating southwest Asia, the Taliban remnants and tribal warlords still are the principal generators of opium and heroin for trade on the open market. Both of these organizations have an obvious stake in ensuring that their products reach their end markets.

Weapons: This project focused on the interdiction of arms intended for the enemies of the United States and its allies. Principal generators of such weaponry include countries like China, Russia, North Korea and Iran. The governments of these countries were stakeholders in this analysis.

Humans/animals: Smuggling of humans refers to both movement of terrorist/insurgent personnel as well as people who are being involuntarily smuggled and people who are being smuggled in order to circumvent normal immigration pathways. The people being smuggled themselves are obviously stakeholders in this analysis irrespective of their intentions. Organizations that facilitate their transfer have a stake in ensuring that they arrive at their destination in order to get paid or to guarantee their good name should payment already have been given. Such organizations might include various criminal organizations such as the Japanese Triads.

Investigation into the detection of smuggled animals was not required by any interested parties. However, any technology employed in the detection of humans will also be able to detect animals. This may be applicable for detecting the smuggling of endangered species. Detection of animals is largely incidental, but not a focus area.

b. Mid-course movement

None of the targeted cargoes are restricted in their movement to only the maritime domain. All of the targeted cargoes can be shipped via land routes, where geography permits, and by air cargo when geography does not permit. A highly successful MIO campaign may cause an adversary to begin shipping illicit cargo via non-maritime routes. This increase in the movement of illicit cargoes by non-maritime routes may cause an increase in the amount of illicit cargo smuggled through land and air routes. Therefore the agencies responsible for border security in a respective region or airport security become a stakeholder. Though none of these organizations would protest a more successful campaign, it is important to note that on a long enough timeline, an effective MIO may cause more materials to move via alternate routes.

During the mid-course movement of illicit goods from source to destination, those responsible for the safety and transport of the illicit cargo are stakeholders. Specifically, the crew of the target ship may be a stakeholder. If the crew is aware of the nature of the cargo being smuggled, they are definitely a stakeholder. If the crew is unaware, they are still a stakeholder. In the event that coalition forces should interdict the illicit cargo, then the owners of the illicit cargo may seek retribution against the target crew's interest or life.

c. Consumers

In the case of smuggled narcotics, a limited supply entering the destination country may place the distributors of such narcotics in a position of being unable to meet their customer's demand. This will cause a rise in the "street value" of narcotics, a rise in crime as addicted customers have to resort to other means to obtain the wealth necessary to make a purchase of narcotics, and potential opportunities for competing narcotic traffickers who had not been interdicted to grow their operations.

For the case of the tools of insurgency, the primary stakeholder is the recipient of such weaponry. As long as an insurgent organization is able to continuously resupply via a sea route, then whatever organization they are fighting will have a difficult time ending the insurgency. In the event that the necessary supplies needed to continue an insurgency are interdicted, then an insurgency's options on how to continue their fight will become somewhat limited.

In all of the above cases, the supplier is a stakeholder again due to the adverse effects that MIOs have on the users of insurgency supplies and narcotics. Should a country like China be supplying arms to an insurgency, and that insurgency fails due to the interdiction of said armaments, then a country like China will be unable to exert their influence.

If a vessel is non-compliant with the MIO process, they may choose to either oppose the boarding team through employment of violent force, or they may choose to attempt to run away from coalition forces. Depending on the perceived threat, national/coalition willpower, and the rules of engagement, it may be necessary to disable that particular vessel. In disabling the vessel, it may be necessary to ensure that a country in the region either take custody of the vessel or be willing to assist in repairs.

Lastly, should a given vessel be deemed too deeply embroiled in illegal activities, it may be seized and the crew detained. At this point, it will be likely that the captured vessel will need to be moved to a friendly country in the region. If no such country exists (and insufficient willpower exists to sink the captured vessel), then it will need to be moved out of the area to a friendly country. This friendly country becomes a stakeholder as they are now responsible for the disposal of the vessel.

d. Ubiquitous Stakeholders

At all points in the movement of targeted cargoes, the US government and its allies are stakeholders. The very creation of narcotics is generally a detriment to governments worldwide. The very creation of the tools of an insurgency for shipment into a hostile area creates work necessary to interdict said cargoes.

During the interdiction of illicit cargoes, there is a clear ‘transfer of value’ that occurs as a coalition Navy takes custody of the illicit cargo.

Finally, should the illicit cargo be successfully interdicted, then there exists a very good chance of second order effects occurring in the destination country. These second order effects potentially impact the United States and its allies. For instance, failure of an insurgency to resupply may increase the probability that an insurgency will collapse. As the collapse of most insurgencies is considered highly desirable, the United States and its allies become ubiquitous stakeholders at all points in the value chain from creation to employment.

3. Functional Analysis

The full functional analysis of all the pieces of “to MIO” is included in Appendix A.

4. Requirements Analysis

Individual requirements for each of the major functional pieces are contained throughout.

5. Architectural Analysis

This section will define the various qualitative measures of architectures. Section C of this report will analyze the degree to which one measure is more important than another. It will also describe four basic architectures and generate a relative score for each of them. This section will also identify the finalized selected architecture.

For the different criteria identified below, a given weight from 0 to 10 is assigned. Table 2 details the relative weights for each of the evaluation criteria.

Effectiveness	10
Crisis Response Capability	9
Logistic Independence	8
Survivability	7.5
Relative Footprint	7
Climate Independence	6
Risk	5.5
Cost	5
Mobility	3
Stealth	2

Table 2: Relative weights for architectural evaluation criteria

a. Architectural Criteria

Effectiveness: While the term “effectiveness” denotes a lengthy discussion regarding Measures of Effectiveness (MOEs), such discussion exceeds the scope of this section of the document. MOEs for individual portions of the system of systems are divided throughout the upcoming chapters. However, the degree to which a system will reliably be able to determine which ship to target for a MIO and be able to locate hidden cargoes without the consent of the target ship's crew is a criterion worthy of general consideration in architectural evaluation.

Effectiveness is given the highest priority for the simple reason that the fundamental reason for doing a MIO in the first place was to accomplish a given mission. Other factors could potentially intervene. However, if an architecture is believed to be unable to even accomplish a mission, then it should be removed from consideration. If ability to be effective at accomplishing a mission is deemed inferior, then the other alternative should still be considered. However, a significant combination of other factors with less weight will need to be able to override a lack of effectiveness to compensate.

Crisis Response Capability: As also required by the project statement, the designed system of systems must be able to respond to regional crisis. It is assumed that the system of systems would need to be able to respond at somewhere from a minimum participatory capacity to something less than the general size of Operation Unified Assistance. That operation was done with multiple coalition vessels, the Abraham Lincoln Carrier Strike Group and both the USS Bonhomme Richard (BHR) ESG. The BHR ESG was later replaced with the USS Essex and USS Fort McHenry.

Crisis Response capability is a more subjective term than "effectiveness" and can be defined to mean many things. As a result, it has been given less priority than overall perceived effectiveness. However, crisis is naturally an opportunity in waiting. There are numerous advantages with regards to being able to respond to crisis, such as humanitarian disaster. Entire regions that may have been previously deemed "staunchly anti-American" can be convinced to be "pro-American" or at least tolerant in a matter of time if the United States correctly positions assets that are flexible enough to respond to different kinds of crisis. Because of the massive fringe benefit in being able to seize an opportunity (i.e. respond to a crisis), ability to handle a diverse array of circumstances is of high priority. Furthermore, the project statement requires that any system of systems developed here be capable of responding to regional and theater crisis.

Logistic Independence: The project requires that the developed system of systems be able to operate in a logistically barren environment. Consequently, the ability of a system to continue functioning as external logistic support is removed is a key factor in rating one architectural alternative over another.

As is required by the project statement, any developed architecture must be able to operate completely without the support of a region of interest. If an architecture requires excessive quantities of supplies and/or personnel to operate, then it should receive a lower score. Logistic Independence is given a higher weight as it is a requirement of the project mission statement, however it is of less importance than being able to accomplish a mission or seize on an opportunity. The employed system of systems is not being employed to demonstrate its logistic independence, as it is there to accomplish a mission that extends beyond the maritime domain. Inability to accomplish that mission negates the necessity of the architecture, regardless of how easily supplied it is.

Survivability: Given the definition of logistically barren, it is a logical conclusion that the area in which the MIOs are to be conducted is distinctly unfriendly to a coalition presence. As a general consequence, it can reasonably be concluded that hostile forces may attack coalition assets performing the MIO. For instance, pirates may attack the boarding team while they are on another ship. Alternatively, a foreign power may choose to interfere with the conduct of the MIO. It is assumed that the designed system of systems ought to be able to withstand such hostile interference.

Implicit in the requirement for the system to be able to operate in a logistically barren environment is that the environment is generally unfriendly.

Either foreign powers, terrorists, pirates and potentially even excessive anti-American sentiment can result in potentially severe damage to an employed architecture. The employed architecture should be able to either survive the anticipated levels of violence, or it should be able to perform corrective maintenance on itself.

Climate Independence: Since nothing about the project statement allows for constraints to be placed on the environment, it can be concluded that the system of systems should be able to operate with equal ability in both day and night. Furthermore, in looking at all of the potential "hot-spots" of the world, they are all capable of receiving foul weather in the form of either typhoons, shamals, high sea-state and/or cold weather.

If an architecture is limited in its ability to perform at night, then other criteria will suffer. Though it might be reasonably effective on average when operating and able to respond to a crisis or be logistically independent, if it is periodically impeded due to weather, then its overall utility is diminished. Climate independence is given a priority, but not as high as the aforementioned architectural evaluation criteria.

Relative Footprint: No part of the US Navy is exclusively devoted to MIO as of the writing of this report. It is the opinion of the authors that the design and construction of a ship specifically to do MIO is a radical step that is not necessary. Instead, the preferred approach is to examine modifications to existing platforms to allow them to be more effective to do MIOs. Minimization of the relative "footprint" on each of the utilized platforms is a highly desirable quality for the designed system of systems.

It is likely that any employed architecture will require an alteration to an existing platform. The degree that an alteration is required to a given platform likely diminishes that platform's ability to perform other functions. However, if the mission is important enough to undertake, it is important enough to undertake it correctly. The relative footprint imposed by the architecture on existing systems is important enough to utilize it as a criterion for distinguishing between alternatives, but in terms of the more mission-centric criteria, it is of less importance.

Risk: Different degrees of technological sophistication are required to implement the different architectures described in section C of this chapter. Two basic categories of risk will be considered here. The risk to the personnel charged with operating the system of systems and the risk that a given system will not be technologically feasible are both considered.

Obviously, a system which has a low risk of failure in its development and does not place any humans at risk is more desirable than a system which fails to accomplish these tasks. However, there is a certain degree of risk inherent in conducting a MIO in the first place. If the risk of doing a MIO were truly greater than the benefits, then the MIO mission would never be ordered in the first place. Therefore, risk posed to humans and risk of developmental failure are given a lower weight.

Stealth: The more a system of systems can conduct MIOs without alerting or interfering with the target population, the more intelligence it will be able to generate while also minimizing risk to the operators of the MIO system. Furthermore, a stealthier system exposes the boarding teams to less risk as they would have an element of surprise. Stealth is also good in the sense that an unsuspecting smuggler may not take as great of precautions in concealing illicit cargo prior to a boarding team’s arrival. In these regards, a stealthier MIO system of systems is more desirable.

However, it is also noteworthy that a stealthy MIO system does little to deter a shipper of illicit cargo. There is also a possibility that the target of a stealthy MIO may react violently, causing boarding team members to be placed at risk. In these regards, stealth is outwardly undesirable.

Lastly, MIO is defined internationally as being an inherently legal action. Inherently legal actions that have the credibility and backing of a body of nations like NATO or the United Nations generally do not require stealthy practices. Because of the lack of an explicit requirement for stealth, and potentially undesirable effects of stealth, stealth is given a very low score. Stealth is still considered desirable due to the fact that publicity concerns about the MIO and its deterrent value can be overcome by public affairs action should that be a requirement.

Mobility: The term “logistically barren” implies that the location for which MIOs will be conducted is not in close proximity to any coalition partners. Thus, the system of systems will need to be able to move to this location. Therefore, the system should have adequate mobility to be able to reach such a destination in a time-span short enough to allow a difference to be made.

As a logistically barren environment is defined as one where there is no logistic support in the environment, and friendly/allied countries provide logistic support, one can very quickly deduce that the logistically barren environment is an operationally significant distance away from anyplace friendly. Since the finished architecture will originate someplace friendly, then there is an obvious need for the architecture to be able to move on its own. However, the time required to make such a transit is not specified in the problem statement. As such, mobility is given a very low score, but is still included for completeness. It is also worth noting that an immobile system should not be considered in this analysis due to the imposed transit requirement.

Four architectures are considered here. They are ESG based MIO (which is essentially the baseline), the submarine launched MIO, heli-borne MIO, and the non-logistically barren MIO.

Cost: As with any other decision alternative, fiscal realities may prohibit realization of a given system. Due to the lack of mention of financial considerations in the project statement, cost will be considered, but not to any significant degree of analysis.

As stated before, if the MIO mission is worth doing, then it is worth funding to the appropriate degree. The appropriate degree needs to be a degree that allows it to accomplish its function. As such, the above criteria are given greater consideration.

b. Selected Architecture

The selected architecture, as described in section C, is the Expeditionary Strike Group (ESG) based architecture.

This 'surface based' architecture will employ small surface craft to transport boarding teams equipped with an appropriate set of equipment to search the target ship in the most expeditious and effective manner possible. The boarding team will have the equipment and tactics necessary to conduct boardings independent of the level of opposition. This boarding team will be supported by a number of UAVs that are capable of rendering disabling fire against a non-cooperative target vessel, as well as being able to conduct ISR over a large area. The relative merit of coalition forces providing various ISR assets of different capabilities will be evaluated.

6. Design Optimization

With the baseline architecture established, there are a number of areas that can be refined. These major areas of refinement mirror the six major functional areas of "to do a MIO" that are discussed in chapter one. For each of the parts of the MIO system, they will be optimized to varying applicable criteria.

For instance, the current baseline (as will be discussed in chapter six) is primarily sailors manually searching through the cargo holds of suspect vessels. Employment of other sensors that can detect explosive residues will greatly improve the effectiveness of such search teams. This refinement increases the overall effectiveness of the overall MIO package.

The individual functional areas each detail their own individual refinements in each of their respective chapters.

7. Validation

Validation of the final engineered product is done first internally by implementing various refinements inside computer models that simulate various pieces of the MIO process. The relative degree to which an engineered improvement generates an improvement in the MOEs of a model will be documented herein.

Validation of results will also be accomplished by the Delphi method (i.e., discussing the final materials with stakeholders, the NPS faculty, and invited guests on the 5th of June, 2008). Alterations and refinements to the report will be made as necessary following this out-briefing and follow-on working groups.

Participating stakeholders have also been provided with draft copies of the report and given ample opportunity to comment. Any irresolvable objections by them have been documented in this report.

Lastly, a copy of this report is posted on the internet and made available for review/comment by any interested parties.

8. Verification

Verification, or the establishment of the truth and correspondence between a product and its specification, can only be done as refinements suggested herein are fielded by operational forces. Surveys of boarding teams, ship’s captains, and operational staffs should help to determine the effectiveness of individual refinements suggested. Furthermore, many of the members of SEA-13 have had either direct experience on boarding teams or managing MIOs at a staff level (in the case of the student project lead).

9. System Operational Use

The system employed will never be one hundred percent effective. In general, the probabilities of interdicting a targeted cargo that may or may not exist on a ship that is not identified in advance are small. The technology and techniques developed in this document are designed to improve these odds; however, it is important to note that no MIO will ever be “air-tight” to a specific type of cargo as long as vessels are allowed to transit.

10. System Retirement and Disposal, Updates

The individual chapters of this paper will document the retirement, disposal and updates of the technologies identified in each of their respective areas.

C. ARCHITECTURAL ANALYSIS

1. Expeditionary Strike Group (ESG) based architecture

An expeditionary strike group consists of a three ship amphibious ready group (an LHD, LPD and LSD class ship), one or more cruisers or destroyers, a supporting logistics tail, and a submarine (in some cases). For the purpose of this analysis, the submarine will not be considered as it is likely that the submarine will be treated as a national asset and will be unavailable for the performance of MIO related functions.

a. Benefits

As a generality, ESGs are very well understood in terms of their flexibility and adaptability. They can do a wide range of missions and are generally well suited to all tasks that are in the “lower ends of warfare”.

b. Drawbacks

ESGs are large and bulky requiring many ships to be effective. They have a high maintenance and operation cost. However, this cost is generally well understood and offset by its multi-mission capability set.

c. Scoring

Effectiveness – 10: Of the architectures considered here, the ESG architecture is able to handle the greatest number of boarding teams, personnel and supporting assets. It has the greatest amount of firepower and the greatest ability to support a boarding team without having to refuel. It also has a good ability to handle confiscated material.

Crisis Response Capability - 10: ESGs have been employed for crisis response in the past. The Bonhomme Richard ESG and later the Essex ESG were instrumental (beyond the Abraham Lincoln Carrier Strike Group) in the efforts of Operation Unified Assistance to relieve the inhabitants of Sumatera from the damage inflicted by the 2004 Tsunami. The Essex ESG was later employed in relieving the inhabitants of a Leyte Gulf village following a mud-slide that covered an entire town. No other architectural concept presented here has the proven track record of ESGs in responding to actual/real-world crisis.

Logistic Independence -8: ESGs still require a logistics tail to support them. However, this process is fairly well understood with a wealth of experience already available. Once supplied, ESGs are likely able to operate for extended periods of time without refueling.

Survivability - 7: Depending on the composition of forces, ESGs lack the kind of the stand off weaponry necessary to survive a full attack by a near-peer competitor. They also do not possess an organic mine-warfare capability. However, in the 2013-2014 timeframe, the ESGs could have an adequate force protection capability, to include a fully fielded Close in Weapons System, block 1B. ESGs also possess numerous Marine Corps assets such as the AH-1 Cobra that can easily neutralize any small threats to the strike group. Furthermore, ESG's also carry hundreds of Marines, many of which will have already been trained to conduct MIOs.

Relative Footprint - 10: ESGs have a lot of area in them for handling everything from UAVs to miscellaneous cargo. Of all the ship classes employed by the U.S. Navy, the amphibious ships of the ESG have the greatest available area for handling modifications relative to their size.

Climate Independence – 10: ESGs can operate in a wide range of sea states and climate conditions. High sea states and typhoons will prohibit an ESG's conduct of operations. However, these conditions will also cause the targeted vessels (particularly if the discussion centers around a vessel that is even less resilient) to divert first.

Risk - 10: As ESGs are a well developed technology, their risk with regards to feasibility is very small. Furthermore, as ESGs do have a great surface lift capacity as well as a vertical lift capability, medical evacuations are relatively easy to accomplish by a variety of means. ESGs also have an inherent hospital capability organic to the LHD.

Cost - 8: ESGs are a sunk cost. The US government has already purchased a number of these and continues to employ them for a variety of purposes. Although their maintenance and operational costs are not inexpensive, it is important to note that this too is likely a sunk cost. Dispatching an ESG to a troubled spot in the world has added benefits besides being able to conduct MIOs.

Mobility - 10: ESGs are intensely mobile. They are a proven technology and routinely deploy from San Diego, Sasebo and Norfolk to areas as far away as the Persian Gulf.

Stealth – 2: Only a vastly technologically inferior entity could miss the presence of an ESG. Their size and composition make them easy to locate using even the crudest of surveillance techniques.

2. Submarine Enabled MIO

As it was desired to develop radically different architectures to evaluate MIO, varying the principal delivery mechanism for moving the MIO package into the logistically barren theater of interest is the primarily altered variable between considered architectural alternatives. Submarine delivery of a MIO package into a theater poses a number of advantages in terms of stealth. However, in other areas, the submarine based MIO has difficulties. In terms of defensive capabilities, a surface vessel is engineered to be on the surface. A submarine does not have this advantage once surfaced. As such, it is assumed in this analysis that in order to do MIOs, a submarine must be able to conduct the interdiction without surfacing.

Furthermore, if a boarding team where to suddenly appear in the vicinity of a target vessel, it would be a strong indication of a submarine being in the area. However, the exact location will still be unknown, and the submarine will still be defended from the target ship by virtue of its depth.

The basic idea behind a submarine enabled MIO is to operate in theater to deliver boarding teams onto target vessels. While not always the case, boarding teams will need to be able to launch while the submarine is submerged in order to preserve the stealth aspect of the submarine. Almost every submarine launched boarding team will surprise the target vessel. This will require the design and construction of a MIO vehicle capable of launching and docking from a submarine.

This will also require the submarine to launch UAVs when submerged in order to provide overhead ISR and large area surveillance. The same UAVs will need to be able to maintain a radio communications link with a satellite equipped with a blue green laser that can talk to the submarine. This will allow the submarine to use UAVs as an ISR asset, or potentially a fire support asset for the boarding team.

a. Benefits

Submarines, particularly nuclear ones, have great mobility, stealth and endurance. They can stay at sea for months on end without degrading their operational capability. They are also generally independent of their logistic pipeline with the exception of disposal of captured illicit cargoes.

b. Drawbacks

Communications with any relevant link from both a tactically sufficient speed and depth will remain a problem for the submarine community for many years to come. Although blue-green lasers have produced some minor results with regards to communications with submarines, this technology has not matured to fruition. In order for the architecture to work, it is assumed that this technological challenge has been overcome. Surface wire antennas could potentially allow for line of sight communications linkages with a UAV depending on the speed and depth of the submarine and design of the antenna.

UAV launches from a submerged submarine open up a variety of different challenges in both the design and construction of the submarine as well as the UAV. Such a UAV will likely be inordinately expensive and complicated with a high failure rate as it would need to be able to both fly at tactically relevant altitudes and speed while also being able to submerge in order to rejoin with the submarine. Alternatively, the UAVs could be disposable such that recovery would no longer be a requirement.

Communications between the boarding team and the submerged submarine will be very difficult. The boarding team will have to rely on satellite communications in order to reach back to the submarine. In the event that a target crew becomes violent, the submarine may be unaware of this event, or unable to respond as the time necessary to send reinforcements will be prohibitive.

Lastly, MIO is not a primary mission area of submarines in the US Navy, nor is it likely that it will be a mission area by the timeframe identified for the scope of this project. It is very improbable that a submarine would be assigned a MIO mission as it will likely receive tasking of higher priorities.

c. Scoring

Effectiveness – 2: A submarine MIO force cannot act as an effective deterrent if any potential suppliers are unaware of its presence. Launching and recovery of a boarding team will likely be greatly more complicated than it would be for surface combatants, which will result in fewer MIOs being done. While the submarine may be more effective in specific scenarios where stealth is paramount, a submarine based approach would be of little value given the average type of MIO conducted at the time of the writing of this report.

Crisis Response Capability - 1: With the exception of a significant Naval incursion by a foreign power, the ability of a submarine to respond to a crisis is somewhat limited.

Logistic Independence - 5: Although a submarine can operate for months on end in the traditional roles of submarines, it cannot conduct an underway replenishment with the same degree of efficiency as surface combatants. The resupply of things like small boat fuel will be prohibitively difficult for a submarine. As resupply will be important (given a submarines relatively limited storage space), a submarine is not given a very high score for logistics independence.

Survivability - 10: Given the relative technological sophistication of modern submarines and their relatively high degree of stealth, the probability that an adversary would be able to render a submarine inoperable from its MIO mission is the smallest for all of the architectures considered here.

Relative Footprint - 0: The number and extent of modifications required to a submarine to allow it to efficiently perform a MIO mission would be greatly prohibitive. Additionally, alterations to the exterior of a submarine require a great deal more engineering than do alterations to the exterior of a ship as these alterations have to be able so survive without compromising the hull while operating at tactically significant speeds and depths.

Climate Independence – 10: Submarines can operate in any condition and sea state. If done at sufficient depth, the launching and recovery of a boarding vessel of some form should also be equally unaffected. Boarding a target ship in high seas will be equally difficult.

Risk - 1: The complexity involved in launching and recovering at depth, conducting communications with the boarding team and surveillance assets, and the communication linkage between a submerged submarine operating at speed and depth are prohibitive.

Cost - 1: Relative to the other architectures considered here, the cost of the modifications to the submarine, and the cost of specialized boarding craft and UAV's that are capable of launch/recovery at speed and depth will be greatly prohibitive.

Mobility - 10: Submarines can traverse a large ocean with equal ease to other platforms.

Stealth – 10: Submarines are the stealthiest of platforms.

3. HVBSS based MIO

This architecture assumes the availability of a ship capable of handling a large number of helicopters, such as a CVN or LHD/A. Even an LPD can handle a significant number of helicopters. It is assumed that rules of engagements are sufficient to allow a helicopter to engage in fire support of a distressed boarding team. It is also assumed that the main platform can be out of visual range from the target vessel.

The basic premise is that a ship with a multitude of helicopters and more boarding teams enters an area and searches merchant ships for targeted illicit cargo. Boarding team members will rappel out of the helicopter onto the target vessel along with all of their search equipment and proceed to search the target ship. Following the completion of the search, the boarding team will then need to return to their ship of origin. Assuming they did not bring a surface craft of sufficient range to transit back (and also assuming the target merchant vessel will not assist in the transit back to the originating ship), then the helicopter will be required to move the boarding team back.

Communications with the boarding team will be very difficult in this environment. Though a helicopter could act as a relay, the probabilities that it would be of sufficient altitude to perform this function are improbable. In order to ensure that communications with the boarding team remain constant, a dedicated airborne relay will be required. Alternatively, the boarding teams will need a satellite communications capability should an airborne relay not be available.

a. Benefits

The principal advantage to HVBSS based MIO is that the MIO can be done independent of sea state, at greater ranges, and on multiple targets. Opposed boardings done from a helicopter are also safer, as there is no requirement for boarding team members to physically jump between craft or to climb high freeboards starting at sea level.

The relative speed at which a boarding team can move from the parent ship to the target ship may give some advantage in the event that the target ship is capable of great speeds.

The larger number of helicopters required to carry multiple boarding teams will provide additional de facto ISR assets.

b. Drawbacks

The consequence of a failing helicopter could be potentially severe. Additionally, conducting MIOs at night from a helicopter will be very dangerous. Rappelling out of a helicopter poses a number of severe risks to the boarding team members.

In the event that an adversary should choose to attack the boarding team while they are onboard a target vessel, helicopters alone may be an insufficient response/deterrent to prevent this from happening. A vessel like a DDG is much more suited for this task.

c. Scoring

Effectiveness – 7: An HVBSS-centric architecture can conduct a potentially larger volume of MIOs than a surface centric approach. However, the high likelihood of failure of at least one part in the HVBSS process as well as the time taken to mitigate the ensuing consequences will likely degrade the effectiveness of an HVBSS based architecture very quickly.

Crisis Response Capability - 8: While an HVBSS-centric architecture has a lift capacity comparable to an ESG, it is incapable of responding to a crisis perpetrated by a foreign power.

Logistic Independence -7: The greatly increased reliance of helicopters on logistic support requires a larger number of spare parts to keep them running.

Survivability - 6: Helicopters are an inadequate stand-off weapon as it relates to surface unit warfare. If the task force were to be pursued by a near peer competitor, it would have a reduced probability of survival relative to that of a surface unit centric MIO force. However, as the term ‘survivability’ relates to the probability that the boarding team will survive, the increased number of helicopters will offer some degree of close air support capability.

Relative Footprint - 7: The helicopters employed will need to be more specialized for rapid egress of the boarding team as well as a more expeditious means of recovery than is currently employed.

Climate Independence – 9: Helicopters require correct winds to recover onboard the launching ship.

Risk - 4: While less risky than a submarine launched MIO, rappelling out of a moving helicopter onto a moving ship that is potentially loaded with hostile adversaries poses an inherently large risk to the boarding team members.

Cost - 9: As stated earlier, aircraft are generally more expensive to operate than surface vessels such as the rigid hull inflatable boats. However, when compared to the overall cost of operating a complete ESG, a pure helicopter centric approach is a single ship and offers some financial advantages.

Mobility - 10: As with the submarine and surface ships, a helicopter carrier is equally capable of making an expeditious transit across a large ocean.

Stealth – 4: While the presence of the helicopter carrier may be generally known to potential targets in a given region, the approach speed at which the helicopter approaches the target ship may allow some amount of surprise of the target ship. As stated in the stealth section for the submarine based MIO, this is not always advantageous.

4. Non-Logistically Barren

The requirement that the designed MIO system be able to operate in a place devoid of logistic support directly necessitated the requirement for some kind of launching platform that could survive in a hostile territory for an extended period of time. Although outside the scope of the problem, it is an interesting exercise to consider totally alternative mechanisms for implementing MIOs should this restriction not have been placed.

If infinite resources were available inside of a given region, ships are not entirely necessary. Small craft can operate from a shore facility at substantially reduced cost than that of a DDG. Additionally, aircraft based on land can provide a credible fire support deterrent towards hostile nations that may intervene in a MIO as well as to the crew of a target ship.

If available, a port facility would be a more ideal place from which to conduct a MIO. If the target ship could be persuaded to pull into a port, then moving large volumes of search equipment, as well as large volumes of personnel who are local to the region to conduct the search, all become trivial matters. Should it not be desired to have a target vessel pull into a port, then swarms of small boats loaded with locally hired contractors could do a very effective MIO.

a. Benefits

The scalability of this approach is limited only to the amount of financial capital available. There is no upper limit to how big an operation can be. This would allow for the largest volumes of MIOs to be done.

This approach prevents the perception of a large U.S. presence as the preponderance of the personnel conducting the MIO would be locally hired contractors. Depending on the area in which this was done, this could be greatly advantageous as a linguistic capability is now available that might not be available to U.S. personnel.

b. Drawbacks

This approach assumes that land based aircraft will be a credible deterrent to ships who may either disobey the directions of small craft operating in a channel. It also assumes the presence of a land base from which large volumes of small craft can operate. This system is totally incapable conducting MIOs away from major port facilities.

c. Scoring

Effectiveness – 9: Given all the assumptions are true, no other system can generate as many MIOs as this system can. However, it is subject to the integrity of the personnel conducting the MIO. They could potentially be in league with whatever entity is the originator of the illicit cargo (i.e. Al Qaeda).

Crisis Response Capability - 0: This approach has no U.S. presence. It essentially is the quintessential outsourcing of a MIO capability.

Logistic Independence - 0: This system fundamentally violates the notion of logistically barren.

Survivability - 5: Personnel are entirely at the mercy of the host nation. However, a potentially greater amount of firepower can be mustered from land. Land based targets are also more difficult to hit than sea based targets.

Relative Footprint - 10: This approach requires no modifications to any existing platforms.

Climate Independence – 4: This system can only operate in conditions that allow the launching and recovery of small boats.

Risk - 6: The loyalty and integrity of the contracted boarding team members could potentially be very embarrassing for the United States and its Allies on a long enough timeline.

Cost - 0: The fundamental principal of this system is that a land base with tactical fighter support, and large quantities of hired personnel are available. Logistic support is not assumed to be given freely from the host country.

Mobility - 0: This system has no ability to transit any operationally sized body of water.

Stealth – 0: The presence of such a force in a host country will likely generate a lot of jobs for the local populace. It will be heavily advertised and very difficult for any intelligence service of any complexity to miss.

5. Architectural Scores

The following table details the scores assigned, their weighted values, and the overall score for each of the four architectures identified above.

	Weight	ESG	Submarine	HVBSS	NLB
Effectiveness	10	10	2	7	9
Crisis Response Capability	9	10	1	8	0
Logistic Independence	8	8	5	7	0
Survivability	7.5	7	10	6	5
Relative Footprint	7	10	0	7	10
Climate Independence	6	10	10	9	4
Risk	5.5	10	1	4	6
Cost	5	8	1	9	0
Mobility	3	10	10	10	0
Stealth	2	2	10	4	0
Weighted Score		9.0	4.2	7.1	4.0

Table 3: Weighted scores for alternative architectures

As can plainly be seen from Table 3, the proposed surface-centric ESG based architecture is the optimum architecture for consideration. Other architectural alternatives are useful only in an academic study and are of such a clearly inferior nature than no further analysis was applied.

III. SCENARIO DEVELOPMENT

A. PURPOSE

The development of realistic scenarios has a two-fold purpose for the project. First it gives a basis to build the simulations around, or it builds the boundaries of our problem to test various different systems versus the current standard systems. Second it provides a chance to research current operations and develop the standard for the next set of solutions.

Our group first decided on an approach to decide the key aspects in defining MIO from a parameter approach. A Causal Loop Diagram shown below as Figure 1, to describe these features graphically. We separated the key parameters into four categories: Equipment Capabilities, Hostile Ship Characteristics, Environmental Factors, and Tactics, Techniques and Procedures (TTPs). In Equipment Capabilities we highlighted the friendly characteristics and how the task of identification is critical to the boarding units. The difference between Detection and Classification is critical when choosing a specific target, where detection is the process of finding "a ship," and classification is the process of finding "the ship." After classification, the ability to intercept a target avoiding capture is also an important operational consideration, but it is also dependent on the hostile ship. The next major area is the hostile or target ship, it has a dramatic effect on the Operations as well as its disposition to passive and active defense measures. Environmental Factors of the Area of Operations (AOR) and the Traffic density are the next driving considerations. These factors affect the force structure and force size and feedback into the TTPs. The TTPs are the local variables to the commander once everything is in place. With all these factors and considerations described, our group started the task of Scenario Development. These scenarios take into account each factor and the critical framing structure which describes the “box” or the scenario bounds. Using these ideals, we decided to use realistic scenarios to support current operations, and to impact current MIO planning in the U.S. and Allied Navies today.

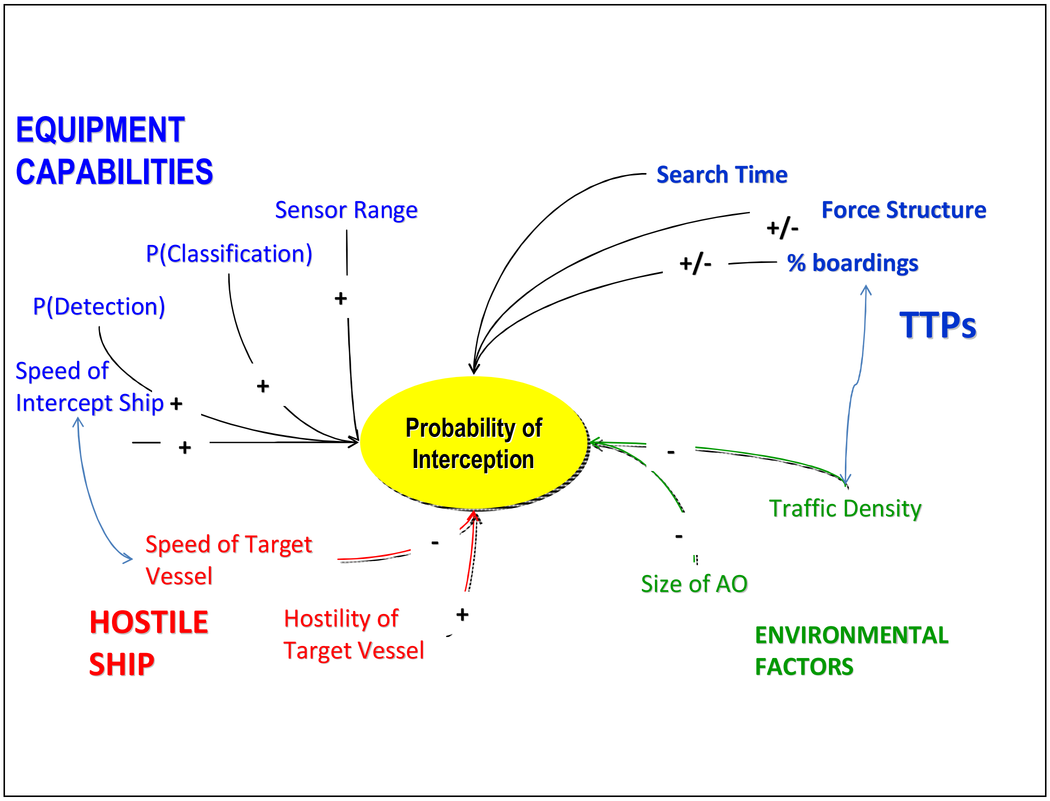


Figure 1: Causal Loop Diagram for Scenario Development

In planning a realistic operation, our group went to the source of U.S military planning doctrine (Joint Pub 5). These scenarios were designed based on the force structure planned in 2013. The scenarios follow a MIO campaign in an Area of Operations (AOR) from the initial stages through Phase 2 in the Joint Publication 5. The following sections will layout the initial set of assumptions and how our team planned the operations based on these assumptions.

B. INTRODUCTION TO COMBINED OPERATIONS

In Joint Publication Five[5], the Phases of Operations are broken down into five distinct phases for operations. The phases take the operations form the first

[5] United States Joint Chiefs of Staff., *Joint Doctrine for Campaign Planning*, Washington D.C., Joint publication 5-00.1, 2002

forces on scene until the eventually turn over to a civilian government or Non-government Organization, which goes well beyond the scope of our analysis. The previous discussion in chapter one describes how we chose to focus on the first three phases, the following is an expansion of those ideas. The group focused on the following phases for the simple reason of the logistically barren consideration in the problem statement. Beyond Phase 2, a significant force structure and logistics pipeline is required to maintain the force, which eliminates that portion of the problem statement. Since the project focuses on logistically barren operations, the decision was made to focus at the initial stages of a Maritime Security Campaign. The post-Phase 2 operations would also probably include a blockade of ports and significant relaxation of the Rules of Engagement (ROE) and definition of hostile targets. This combined with wording in the Joint Publication which requires the establishment of logistics hubs by the end of Phase 2. This critical planning objective caused our group to develop the first three phases for the project scenarios.

Using this as a guide the operations management group established a Concept of Operation (CONOPS) for each phase and a general CONOPS for any MIO campaign. A summary of the CONOPS states that we intend to conduct Maritime Intercept Operations around the globe with zero friendly losses. The CONOPS details the enemy and friendly centers of gravity and gives insight into the organization structure required to fight. The CONOPS focuses on perceived results since the actual measurement of smuggled cargo is impossible to verify, but other critical factors can influence the operations. The CONOPS is designed for flexibility with the following scenarios built off the general CONOPS. The major goal of the operations is to conduct effective MIO operations anywhere at any time.

The actual CONOPS is located in Appendix C; the following paragraphs describe the scenarios with respect to the three Phases each having a corresponding scenario. Although the phases would be planned in a sequential manner, for this project each phase is its own independent event. Instead of setting probable time length for the scenario events, we chose to think of each as separate event with its own problems and solutions. This caused the creation of three separate scenarios with differing force structure, objectives, and test variables. Each phase is independent to define clear modeling problems to focus on certain solutions and critical factors. For example the Phase 0 scenario focuses on specific targets and specific search units rather than search time for the boarding party. The Operations Management group also looked at how the operations would progress through each phase. By doing this we highlighted various events or "trigger states" that would cause a commander to request the additional or reduction in force structure to transition the operation from one phase to another. It is important to remember that each phase is independent and does not necessarily have to be completed sequentially or in a forward direction. The commander may decide the operation has reverted to a previous phase or the objectives of the campaign were met or are now irrelevant. The CONOPS gives detailed information on Commander's Intent and how we plan to organize the operations for success.

C. BACKGROUND

With the increasing use of global shipping lanes and the ability of criminal and terrorist organizations to possibly project power through the shipments of illicit materials, global navies are now required to protect and patrol this valuable asset. In the last 10 years three major maritime incidents, the French *M/V Limburg* in the Bar-el-Mendeb, the attacks on Iraqi Oil Platforms in the Northern Arabian Gulf, and the Piracy attacks off the coast of Somalia stress the need for navies to take a proactive stance in areas to deter terrorist and criminal organizations from disrupting or exploiting the shipping lanes. Although Maritime Interdiction Operations are conducted at sea we are cognizant that many of the primary effects are ashore directed at the groups and organizations using the busy shipping lanes to disguise their illicit cargoes. Using MIO as a deterrent to these organizations is a way navies can protect their trade interests, critical shipping lanes, and their citizens from disruptive groups. Looking at the previous recent examples and the increasing threat, MIO are now an important piece in the current struggle to protect national interests and the global economy.

This new mission area while difficult can be the focus of major operation just as Anti-Submarine, Strike, and Air Warfare have been in the past. This means that navies need to be ready to deploy and project power into busy shipping lanes to protect the interests of their nations. Our scenarios are focused on how we think a coalition including the U.S. Navy would establish a MIO campaign in a busy shipping lane to intercept targets of interest labeled “Red” shipping. This scenario is purely fictional, and purely the creation of the authors and any similarities to current plans or operations is purely coincidental. The countries and assets represented are simply representative platforms and do not have the full capabilities of the actual platforms.

D. SCENARIO SETUP

For our scenarios we chose a fictional map based on a part of the world where there is relatively low shipping traffic. The map of the Area of Operations is shown in Figure 2. The area is bordered by major shipping lanes and five major countries/groups. The shipping lanes are critical choke points and have arrival/ departure rate of approximately one ship every five minutes, which is a very dense traffic pattern similar to the Straits of Malacca. There is also heavy regional and coastal traffic with over one-thousand smaller vessels present at any time. The large amount of traffic also tends to attract pirates and petty criminals to the maritime environment.

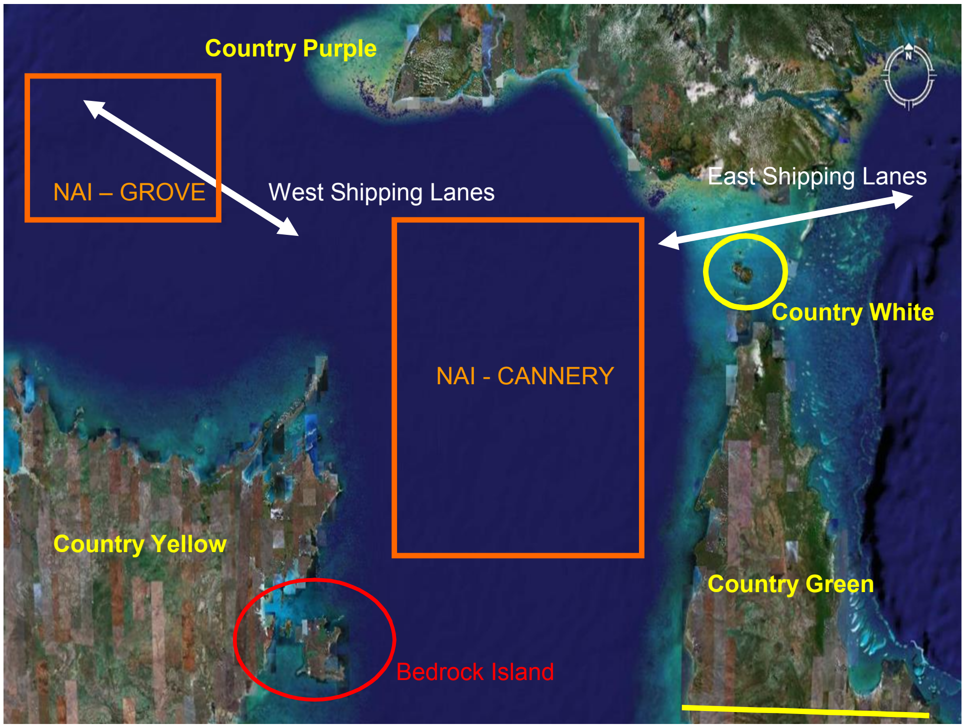


Figure 2: Map of Scenario Region

1. Political Background

The area is surrounded by five major political players who each have an interest in the region, and differing abilities to project naval power into the shipping lanes.

a. Country Purple

Country Purple is a non-allied country who does not have a major economic stake in the straits. They depend mostly on the ocean for a source of internal needs and do not have a major shipping industry. The do not oppose the operations in the straits but will not send units to support it either. Their units will continue to do anti-piracy patrols, fisheries enforcement, and other normal coast guard activities, which may encompass MIO in the form of custom inspections. These MIO will not be helpful to our operation since Country Purple will not report details of the boardings. Also some local officials may not be under the control of the central government and conduct MIO operations for local or monetary benefit.

b. Country White

Country White is a small island nation located at one entrance to the straits. Country White relies on the straits for a high percentage of its economy and has the busiest port along the straits. It is very friendly to the ongoing operations and will support the coalition if the threat is substantiated. Country White has a modern military with significant ISR and AEW assets that could be useful to the operations.

c. Country Green

Country Green is a large nation along the Eastern Region of the shipping lanes and has been a perennial ally of the United States. Country Green has a major stake in the shipping lanes both economically and politically. U.S. and Country Green units often participate in regional exercises and the U.S. has air and ground units deployed in-country almost year round, while naval vessels make routine port visits during the year. Country Green is friendly to the U.S. and will support any operations in the area.

d. Country Yellow

Country Yellow is a large nation who sometimes views U.S. actions in the region as “interference.” Country Yellow is currently experiencing a violent internal war and a separatist group has seized part of the country and continues to try and overthrow the current government. Country Yellow is completely involved with keeping the population safe and will not support any operations that do not directly benefit the current government. Country Yellow is distracted and will not oppose any operations but requires U.S. / coalition forces to respect its sovereignty.

e. *Separatist Group (Bedrock Island)*

The Separatist Group in the area has seized a large country Yellow offshore island, Bedrock Island, and has set-up an ad-hoc government. The separatist group wants to expand its political control in to Country Yellow as well as the greater region. Its leadership has broadcast its intentions to use shipping lanes, terrorism, and other disruptive operations to achieve their goals. The Separatist group is also supported by outside countries and its primary source of material is from the sea. The goal of the operation is to prevent the Separatist Group from influencing the politics and security of the region through the shipping lanes, and to interdict supplies being moved to the separatist group.

2. Scenario Story Line

The impetus to conduct a large scale MIO campaign is caused by the Separatist Group seizing the island from Country Yellow. The Separatist are using this island as a base of operations with a goal of instilling their beliefs into all the regional countries. They see the economic influence of "Western" Countries as bad influence for the region. They are using the shipping lanes to send out supplies to splinter groups in the region and to receive supplies from sympathetic groups/governments from outside the region. U.S. intelligence predicts that initially the group will use regional and international carriers to move supplies through the region.

U.S. intelligence has collected information on several splinter groups in Country Purple and Country White that have increased activity. These groups have new weapons and money to recruit for their organizations. Since no air traffic or ground traffic with sufficient capacity has left the separatist island, intelligence has concluded the sea lanes must be the source of the new equipment in the region. Also Country Yellow State News reports and state department sources have the separatists using state-of-the-art equipment built in foreign countries. This equipment is being used to maintain the separatist group dominance of Yellow forces, and is not produced locally to the region.

Sympathetic countries outside the region are shipping supplies, weapons, and personnel to the island against regional and international regulations. Country Green and White intelligence have noticed an increase of traffic through the shipping lanes destined for Yellow and Separatist ports. Also there has been an increased number of containers intercepted at large regional port hubs with incorrect contents and documents suggesting smuggling of dangerous cargoes to the region.

This information has caused regional government groups to appeal to the United Nations and Allied countries (including the U.S.) to assist in preventing dangerous cargoes from entering or leaving the area. Also with increased number of targets and lucrative cargoes, pirate attacks have increased including attempted attacks on U.S. flagged vessels. The President of the United States with the support of the regional governments has deployed the *Bon Homme Richard* Expeditionary Strike Group to the region to protect U.S. and allied shipping interest in the region.

3. Area of Operations Assumptions

The U.S. - Country Green relationship is a long-standing allied relationship that will allow U.S. units to use Country Green as a logistic depot. Although the government of Country Green will not initially actively support the operation, it will allow supplies and logistic ships to use seaports and airports for the units in theater. Country Green is approximately a twenty hour flight from major U.S. West Coast cities (Los Angles, San Francisco, etc) and a fifteen hour flight to Honolulu. Country Green is also approximately a ten hour flight from the largest forward deployed logistic hub. The U.S. has detached an Expeditionary Strike Group (ESG) to the area and it is supported by a typical logistic ship detachment. A T-AO (Navy Oiler), T-AFS (Naval Supplies Ship), and T-AE (Ammunition Ship) are present in the area and will re-supply the ships as part of normal operating procedures for deployed Strike Groups.

4. MIO Targets

As part of the operation the U.S. units will be searching for four main cargoes on the vessels: Weapons, Explosives, Drugs, and Human Traffic to and from Bedrock Island. Weapons will be defined as guns, mortars, and other conventional weapons, while explosives will be material such as C-4, Mines, and Improvised Explosive Devices (IED). Each vessel in the AOR will be put into one of six classes found in Table 4 below.

Class	Size	Typical Vessels
I	< 300 Tons	Trawler, Fishing Dhows, Tugs & Tows, small Cargo Ships
II	< 300 Tons	Passenger Ferries, Car Ferries
III	> 300 Tons	General Cargo, Cargo Dhows, Small Coastal Traffic
IV	> 300 Tons	Ore, Bulk, Oil Carriers, Large Tug and Tows
V	> 300 Tons	Passenger Ferries, Cruise Ships, Roll-on Roll-off Ships (RO-RO)
VI	>300 Tons	Container Ships, Large Container Barges

Table 4: Ship Classification Categories

5. Blue Forces

The Blue Forces currently on-scene is a U.S. ESG which includes a Large Deck Amphibious ship (LHA/D), Landing Ship Dock (LSD), Landing Platform Dock (LPD), three Guided Missile Destroyers (DDG), and a Guided Missile

Cruiser (CG). All platforms have three Visit Board Search and Seizure (VBSS) Teams with the exception of the LHA/D which has four teams. All ships except one DDG have two SH-60R helicopters onboard and two small Rigid Hull Inflatable Boats (RHIBs) to deliver the VBSS team to the target. In addition our group will test the benefits of substituting the SH-60R and one RHIB with UAV detachments and USV detachments. Currently the UAV detachments will be three Vertical Take-off UAVs (VTUAVs) with an expected sortie of two per mission and one USV which will be force multiplier, but limit the ships to one RHIB to conduct boardings. This replacement of SH-60s and one RHIB is known as the MIO Mission Package and will replace the normal load of two RHIBs and two SH-60 Seahawk helicopters. The MIO mission package is the standing force for all scenarios; allies will add forces and some forces will not be utilized in the operations in all phases. A detailed look at the model variables and definition is further discussed in chapter eleven. Our title for the campaign is OPERATION ACADEMIC FURY, and full detail of the planning, mission areas and commanders' guidance can be found in the Concept of Operations (CONOPS) document located in Appendix C.

E. PHASE 0: SHAPING THE MARITIME ENVIRONMENT

Phase zero is the initial phase of the operation with limited force and objectives. The trigger states to establish the operation or campaign are very limited. The major purpose of the initial phase of the operation is area familiarization and establishing a presence. The initial MIO are to establish the predicted threat and protect U.S. shipping in enforcement of international sanctions on the Separatist Group, giving the legal foundation to the operations. Phase zero is the starting point and an operation that could be conducted anywhere in the world with a small force and heavy traffic.

1. Phase 0: Trigger Stats

To establish this type of operation, increase in port security or IMO reports on smuggling in an area or intelligence on shipping containers being used as smuggling medium. Also any pirate or criminal attacks on U.S. or allied flagged vessels in the region would cause an immediate response from the Navy. Lastly any increased abnormal shipping traffic activity, for instance not using AIS transmitters, refusing to acknowledge VTS, or merchant vessels changing flags in the region would demonstrate illegal shipping activity in the region. These previous events would cause local governments or a regional cooperation group to enforce stricter monitoring and enforcement of maritime law. Any of these would result in the U.S. ESG deploying to the region to deter further unlawful or de-stabilizing activities and to protect U.S. flagged vessels and U.S. economic and shipping interest in the region.

2. Scenario 0: Overview

Scenario 0 is the first scenario used for modeling and simulation and is a search and board problem in a busy shipping lane. For this scenario the U.S. ESG is on-scene to the South conducting operations and has detached a Surface Action Group (SAG) to the north to monitor the shipping lanes. This blue force SAG will be two U.S. DDGs with Helicopters or UAVs operating independently in the shipping lanes to find a targeted cargo ship. The target ship will have a known identity from an intelligence report, or the DDGs/ Aircraft will know the target by a visual scan. The target will be a compliant boarding since most large registered cargo ship will stop due to insurance concerns, and probably have no knowledge of the illicit cargo. A U.S. P-3 detachment will also be available from Country Green to assist in the search for the target ship. On the map in Figure 2, the operation will be conducted in Named Area of Interest (NAI) Grove which is approximately 200nm x 200 nm. Different caveats and scenario test plan will be discussed in the Model and Simulation Section.

F. PHASE 1: DETERENCE OPERATIONS

Phase one is the second phase operations designed to project power against both the large commercial shipping in the normal lanes as well as the smaller coastal traffic . Phase one is a fundamental shift in tactics that relies on quantity of boardings rather than quality of targets in the previous scenario. The increased mission also increases the basic unit of force to an U.S. ESG instead of just a SAG with additional allied ships and aircraft joining the operation. The operations will be conducted in NAI Cannery which approximately 300 x 500 nm box in the southern part of the map (Figure 2). This phase will be a scenario for modeling and simulation.

1. Phase 1: Trigger States

As stated in the introduction, no expected time is planned to transition between phases; instead each phase is evaluated as a separate operation with its own goals and force structure. Some circumstances could cause an enemy to move from large container ships to smaller cargo/coastal ships include the following: First the increase in port security or port security alerts through the IMO insurance agents. Increased pirate activity reported in the area may be a sign there are easy lucrative smaller targets in the coastal shipping lanes. Any success in the previous phase may cause the enemy to change tactics and try to disperse its shipments into smaller more plentiful coastal craft. Another example is more definitive action from regional or global security organizations for example the United Nations or ASEAN. Any of these could cause a shift in tactics which the Allied naval force must be ready to counter.

2. Scenario 1 Overview

This is the second scenario for Modeling and Simulation, and it will have increased force structure and target set. There is also a more obvious role of the allies in actual boarding units in the scenario. The entire U.S. ESG will be available and up to two coalition ships for a total of six Boarding Assets to participate in operations. All ships have either the MIO Package or helicopter assets depending on the test object for the scenario. Also an Airborne Early Warning Aircraft (AEW) will be available for a long range link relay to maintain the contact picture while search assets continue to search. The targets will be high density coastal craft with cargo dhow properties, relatively slow and smaller craft which will take less time to board. The density will be in excess of the boarding ship's capability with a fixed percentage of Red traffic intermixed-with neutral traffic. Red and Neutral traffic cannot be determined before a boarding team is sent to board the target. Country Green will supply the base for the MPA (P-3C Orion) and one boarding ship modeled as an Oliver Hazard Perry Class frigate. Country White will supply the base for the AEW aircraft and one Corvette modeled after the Royal Singaporean Navy's Formidable Class. The objective of the scenario is to board all white and red targets in the twenty-four hour time period.

G. PHASE 2: SEIZE THE INITIATIVE

Phase two operations are designed to impose the will of the allied forces in the area of operations, and to increase operational tempo of the operations to stop the Separatist group from spreading through the region. Phase two is a continuation of Phase one, but with new threats in the area. The change in red from compliant to non-compliant to hostile, as allied forces begin to interdict large amounts of cargo. Also the possibilities of Waterborne Improvised Explosive Devices (WBIEDs) are also introduced in this phase. Also by the end of Phase two in actual operation, a variety of military branches (Air Force, Army, Marines) would also be involved, with the potential for large scale military interdiction and strikes. Scenarios will not be built for beyond phase one since the operations are no longer considered “logistically barren” in practicality. Phase two is described for the purposes of completeness and to fully evaluate the performance of the system of systems of in transition to non-logistically barren phases of operation.

1. Phase 2: Trigger States

As was the case in the previous phase, no expected time is planned to transition between phases; instead each Phase is evaluated as a separate operation with its own goals and force structure. Phase two marks a different strategy for the Separatist Group as they move to more offensive tactics to break the MIO operations and the trigger states will also be more distinct. First would be the number of craft who are no longer "compliant" in dealing with the Allied force or the number moving at night. Also an increased number of "go-fast" boats or smuggling craft that have short range but high speed crossing the MIO operations area. Also as before, if the allied MIO operations are successful, then the enemy will change tactics to avoid the course of action. With the introduction of WBIEDs MIO forces will have to take greater care in choosing targets and maintaining proper military posture to avoid casualties. The increased role of a regional or national group (U.N. or ASEAN) could also prompt different action from both sides. These trigger states are a guide for the tactics shift in both sides for the next phase of operations.

2. Scenario 2 Overview

This scenario was not chosen for Modeling and Simulation due to the lowered priority of less logistically barren scenarios. Instead the greatest focus was on the compliant / non-compliant boarding scenarios in Phase 0 and 1, instead of the opposed boarding scenarios in Phase 2. Planned information can be found in the CONOPS in the APPENDIX and Scenario Power Point Slides.

H. CONCLUSIONS

By using actual U.S. planning documents for a MIO Campaign, a degree of realism is inserted into the scenarios. Using the given timeline of 2013-2014 and our guidance recommendation could effect deployments immediately since no "new" units were modeled. These scenarios are also representative of current MIO operation including the Horn of Africa, Straits of Malacca, and Gulf Guinea operations. The Modeling and Simulation Section will detail the test plan and points of departure from these baseline scenarios for further studies.

IV. OPERATIONS MANAGEMENT

A. INTRODUCTION TO OPERATIONS MANAGEMENT

Operations Management is the critical function in operations planning and execution. The previous section of Scenario development was just one of the many functions for the Operations Management Group. Our role covered the entire spectrum of operations from development of low-resolution combat models, mathematical approximations, and developing the planning consideration for a campaign staff. The group is comprised entirely of military officers: two from the Singaporean Army, one from the Singaporean Air Force, one from the Israeli Army, and two from the U.S. Navy. Our wide range of background and operational experience made us keenly aware of the breadth of planning and operational considerations for large operations.

We focused on three major areas, low resolution model development for priming a large simulation, creating MIO contingency plans, and development of scenarios/ CONOPS. The low resolution development was focused in two areas: creating a mathematical queuing theory model, and simulation with base scenario in the MANA language. The development of contingencies was to plan for events that we were unable model and to identify areas that require study beyond the scope of our project. The development of scenarios and the CONOPS can be found in the previous chapter.

B. MAP AWARE NON-UNIFORM AUTOMATA (MANA) SIMULATION

1. Overview

A Low Resolution model was created to provide a general understanding of the effectiveness of a force package in conducting Maritime Interdiction Operations (MIO). The Low Resolution model only focused on current force structure to validate the current systems and to provide a point to diverge. By building this scenario we could validate the "base" scenario from the previous chapter. These results were critical in testing the feasibility of scenario force structure and current operations today. An agent based simulation program, MANA (Map Aware Non-Uniform Automata) was employed for this low resolution model. MANA was chosen due to the versatility of the language and the ease of development of simple scenarios to test assumptions. The agent based simulation is also good for gaining insight into the initial assumptions, and the development of the scenario test plan. Although its lack of detail and data outputs eventually drove the group to choose a different simulation system.

2. SCENARIO DESCRIPTION

The scenario was based on Phase 1 and involved the searching and boarding of ships in the NAI Cannery, a 300 x 500 nm area. The search is carried out in 3 sub-regions equally divided in the area of operation. 100 compliant ships are randomly distributed in the entire area traveling to their destination either to the east or west. Ten ships are non-friendly: ships that are targeted to be searched and seized for illegal cargo, these 10 represent 10% of the total traffic in the NAI.

The Reds' objective is to pass through the narrow channel from east to west. The Blues' objective is to intercept the Reds before they reach their objectives. The Red forces need to be boarded and searched before they can be determined if they are friendly or non-friendly. The force configuration is 2 intercept ships and an Aerial Search Vehicle (ASV) per MIO box. Figure 3 below shows an initial setup of the model in MANA.

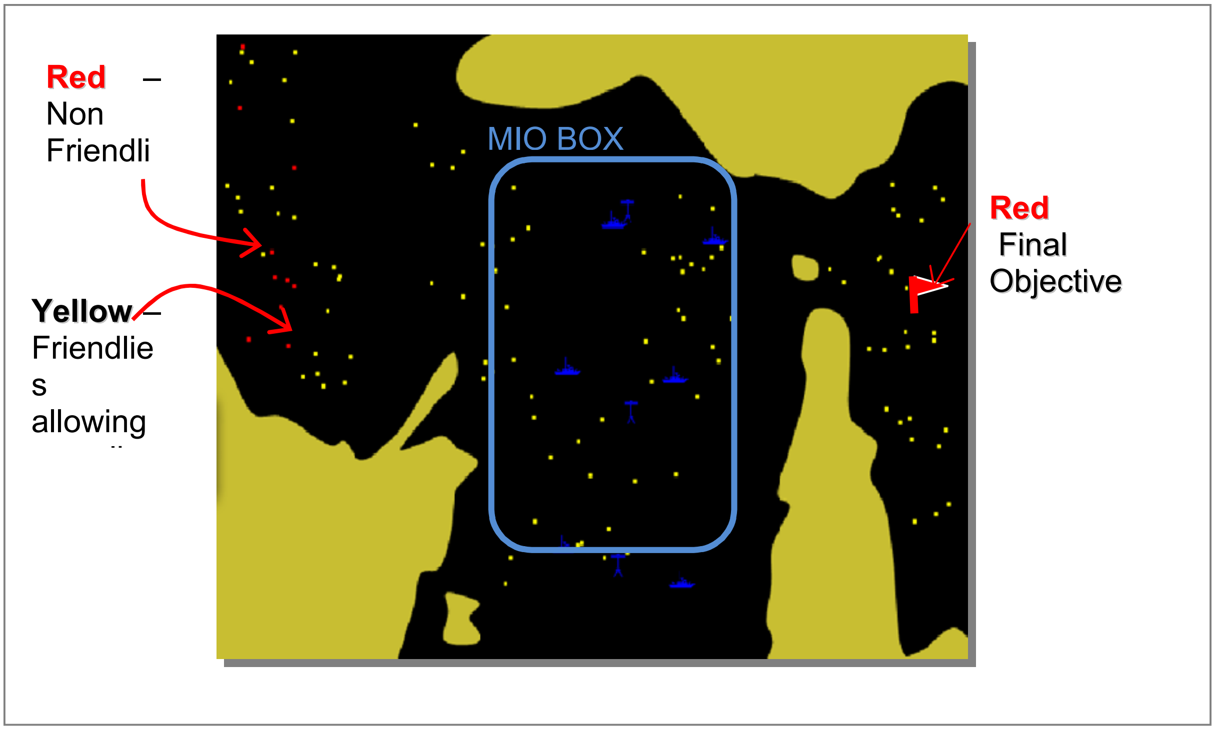


Figure 3: MANA Display of Low-Resolution Model Setup

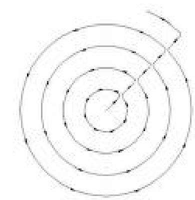
3. KEY MODEL ASSUMPTIONS

The following assumptions are made in the creation of the model. The 2 main categories of the assumptions are for Tactics, Techniques and Procedures (TTPs) and Equipment capabilities detailed as follows:

a. Red Vessels Behavior

The red vessels are assumed to pass through the channel at a rate of one every 25 minutes, up to 10 vessels. The Red Vessels will attempt to avoid Blue intercept ships

b. Tactics, Techniques and Procedures



Since the scenario size is 300nm x 500nm and the vessels travel at 20nm/hr, the Red vessels will be able to reach their objective within 10-15 hours. After the Red vessels reach their objectives, the Blue intercept ships are considered to have failed in their objective to interdict the Red vessels.

The search pattern here employed is the spiral search pattern. The Aerial Search Vehicle (ASV) will spiral out from the center of its position outwards to search for vessels to board. Upon detection of a vessel, the ASV will deviate from its search path and track the vessel until it is boarded by an intercept ship. This spiraling search pattern is done within the boundaries of the MIO box. The spiral search pattern was chosen for its effectiveness and simplicity to model. Aircraft have a significant speed advantage over the Red craft and the spiral search is effective in this case.

All ships that come within the intercept ship range or are tracked by the ASV will be boarded. Regardless of size and tonnage, it is assumed that it will take the boarding teams three hours to board and search the vessels.

c. Equipment Capabilities

The aerial search vehicle is capable of detecting and classifying with certainty (Probability of detection and classification = 1.0) up to a maximum distance of 6nm. Aerial search vehicle has endurance of 3 hours and takes 15 minutes for refuel. It is assumed that the intercept ships are able to operate for more than 24 hours. Hence with the scenario being run for durations of 24 hours only, there is no need for the refuel of the intercept ships. All vessels (friendly, non-friendly and intercept ships) travel at 20nm per hour and the aerial search vehicles travel at 200nm per hour.

3. MEASURES OF EFFECTIVENESS

Interception is completed when the intercept ship successfully boards and searches the red vessel after the red vessel has been tracked by the ASV. The probability of intercept is measured by $\frac{Number\ of\ Intercepted\ Red\ Vessels}{Total\ Number\ of\ Red\ Vessels}$.

4. RESULTS

A total of 30 runs were made to ascertain the probability of intercept. From the results we can see that for such a force package, the probability of intercept is less than 50%. The average probability of intercept is 0.41 with a standard deviation of 0.198

C. DISCRETE EVENT SIMULATION

The Discrete Event Simulation or Queuing Theory model is the most flexible model developed by the team. It focused on two-area search asset utilization and search asset prediction for target excess environment. The utilization model focuses on how assets are utilized in a 24 hour period, and how much "idle" time the units have during the operation. The second model is to test the effect of a search asset on target excess environment, which can help predict the loss of units due to operating in a logistically barren environment. The DES program was chosen due to the ease of changing variables and output flexibility. The SIMKIT JAVA add-on is specifically designed for real-time simulation, and the queuing theory model is similar to many validated customer service models.

1. Utilization Model Overview

A Queuing model was created to provide a general understanding of the requirements of the force package in conducting Maritime Interdiction Operation (MIO). This first model attempts to describe how a force can board a certain percentage of traffic, for example the Phase 0 scenarios. A DES (Discrete Event Simulation) program, SIMKIT is employed for this low resolution model.

2. Scenario Description

The scenario involved the arrival and boarding of ships in a fixed area of operations on a particular 24 hours interval. Ships arrive to the designated area of operations randomly at various rates. Ten percent of the ships in the area are targeted to be searched for illegal cargo. The objective is to assess the minimum required number of boarding teams to support the MIO.

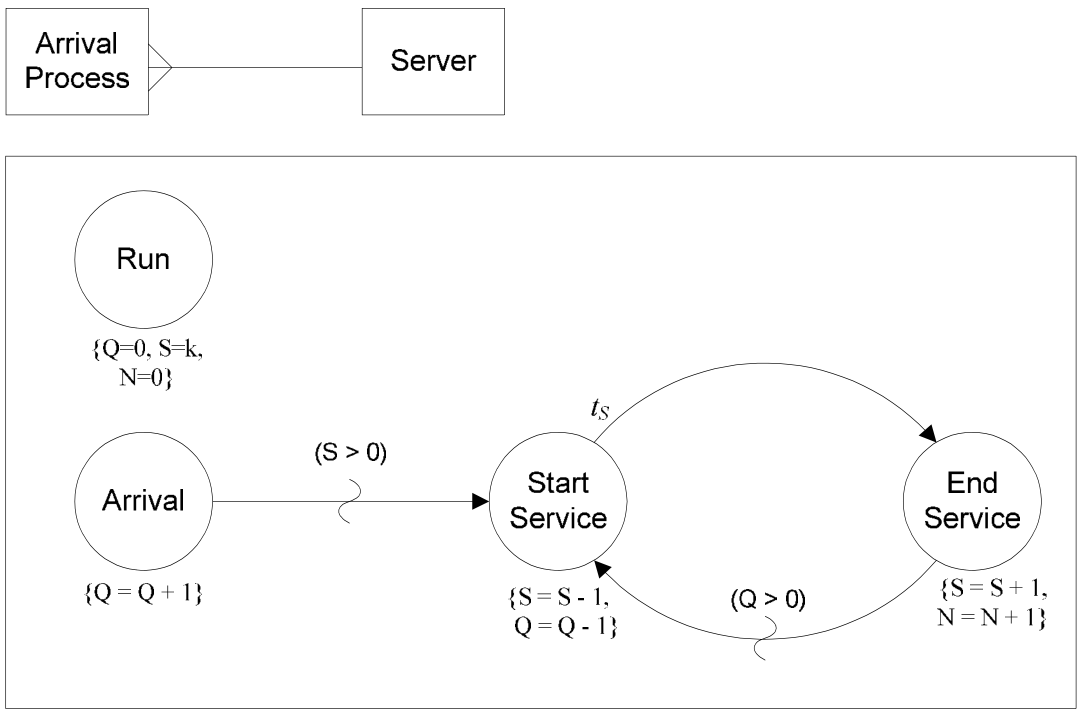


Figure 4: Event Graph of Ship Server

3. Key Model Assumptions

The following assumptions are made in the creation of the model. The two main categories of the assumptions are for Tactics, Techniques and Procedures (TTPs) and Equipment capabilities detailed as follows:

a. Ship Arrival

Ship arrival is assumed to follow Poisson distribution with mean of 24, which is consistent with the arrivals through busy shipping lanes. The data was estimated from VTS reports at Port Kelang in the Straits of Malacca[6].

b. Tactics, Techniques and Procedures

The simulation is based on a 24 hour period. The traveling time from target ship to target ship is included in board and search time. Ships that arrive within the area of operations are boarded randomly with 10% probability. Regardless of size and tonnage, it is assumed that it will take the boarding teams three hours to search the vessels, inclusive of travel time to another ship if boardings occur successively.

4. Measures of Effectiveness

a. Average Utilization Rate

Average utilization is defined as the average percent of time the boarding assets or servers are busy per server. That is, the average number of busy servers over the time specified divided by the number of servers. The ideal average utilization rate is approximately 1.0 where the minimum number of servers is fully utilized.

b. Number of Ships Served

The ideal number of ships served is 10% of all the ships that arrived (chosen randomly).

[6] KLANG VTS report, Government of Malaysia, 2007.

5. Results

A total of 50 runs was made to ascertain the average utilization rate and number of ships served, to provide a convergence point within the Central Limit Theorem. From the results in Figure 5, we can see that for one boarding asset, the average utilization rate is approximately 90%. The average percentage of ships is 15%. For two boarding assets, the average utilization rate is approximately 75%. The average percentage of ships is 28%.

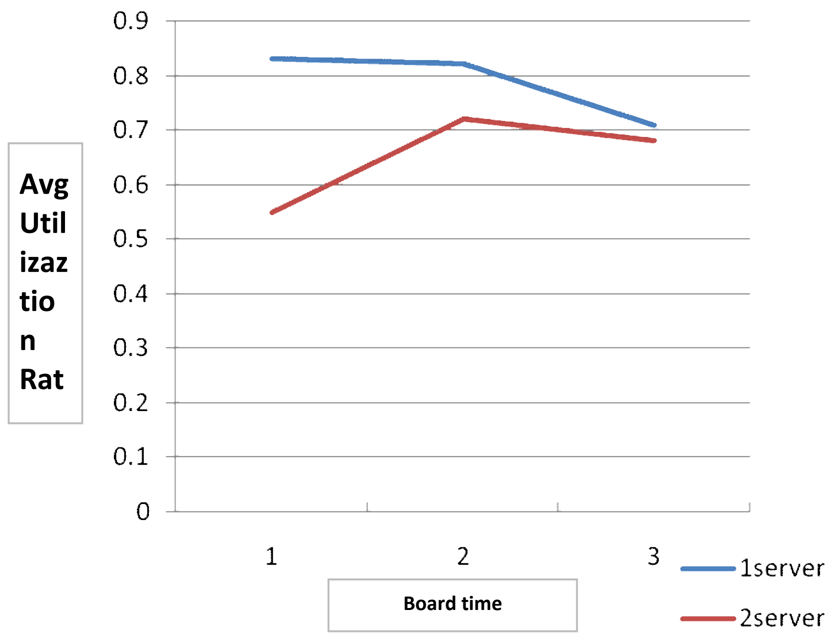


Figure 5: Output of Utilization for Boarding Assets

D. ASSET PREDICTION DISCRETE EVENT SIMULATION

1. Prediction Model Overview

A Queuing model was created to provide a general understanding of the requirements of the force package in conducting Maritime Interdiction Operations (MIO). The Queuing model also provided estimates of loss of forces in the MIO environment and answers to many logistic questions on the loss of a search asset. This model parallels Phase 1 scenarios with a target excess and a varying number of boarding assets. A DES (Discrete Event Simulation) program, SIMKIT is employed for this low resolution model.

2. Scenario Description

The scenario involved the arrival and boarding of ships in a fixed area of operations on a particular 24 hour interval. Ships arrive to the designated area randomly and at various rates. This model holds the arrival rate and expected search time constant and looks at the effects of adding and subtracting a boarding asset.

3. Key Model Assumptions

The following assumptions are made in the creation of the model. The two main categories of assumptions are Tactics, Techniques and Procedures (TTPs) and Equipment capabilities.

a. Ship Arrival

Ship arrival is assumed to follow Poisson distribution with mean of 1 ship every 7 minutes, which based on the Port KLANG VTS.

b. Tactics, Techniques and Procedures

As in all previous models 24 hours is the standard time for operations. In this model the boarding time is held constant to three hours, as the average time to search a Cargo Dhow.

4. Measures of Effectiveness

a. Number of Ships Served

The number of ships served by number of assets available is the key measure of effectiveness to show the commander an approximate upper bound on total boarding operations during that 24 hour period.

5. Results

The results are shown in the figure below, highlighting the average number of units boarded averaged over one hundred runs of the queuing model. The model shows an almost linear response to vessels boarded as a function of search assets. The additional line in the figure is the simulation data from the Naval Ship Simulation language to be discussed in detail later. The data supports the chapter eleven NSS data and by adjusting the search time to actual operational times, this model can give good approximations to the total boardings by a force. This model is best used in a "target excess" case where the boarding assets do not spend a significant amount of time transiting between targets. In the larger scenarios where the traffic has differing transit times, another mathematical model should be used but was not created for this project. This model does approximate the loss of assets on the mission which is critical in the logistically barren environment.

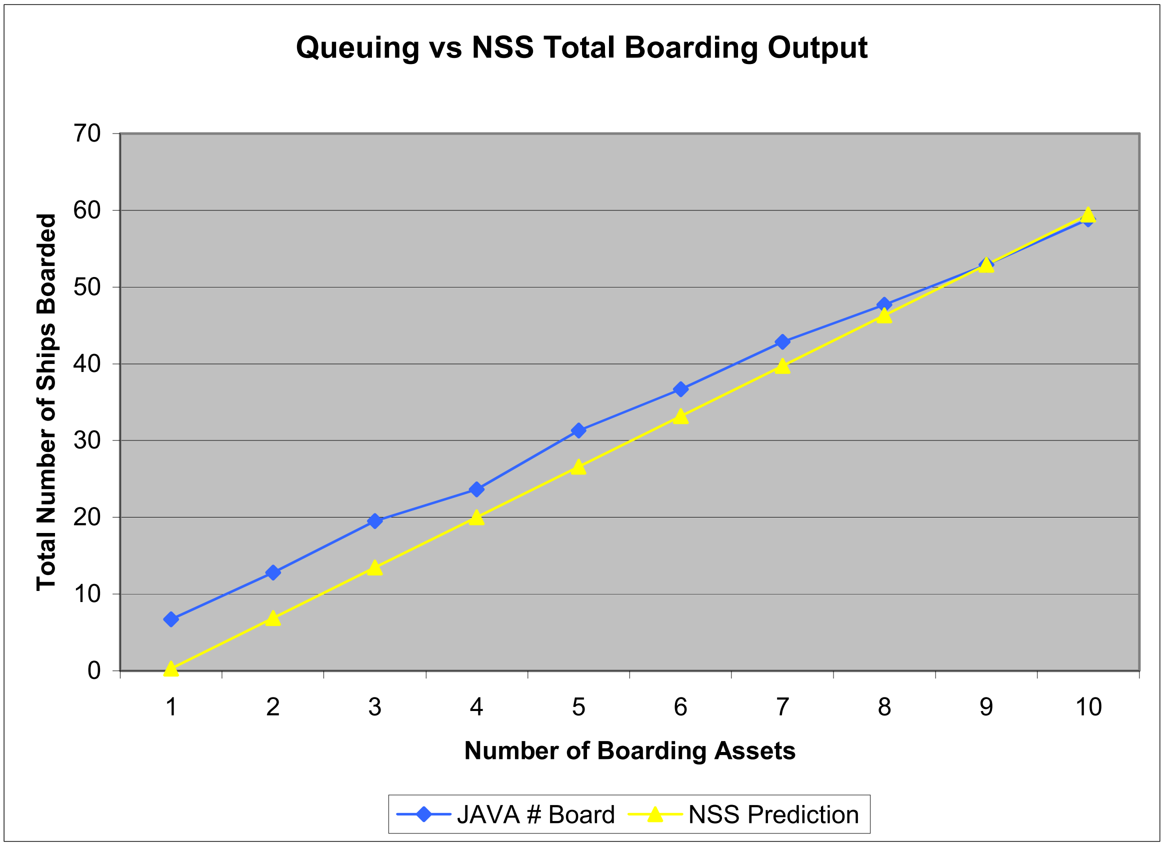


Figure 6: Total Boardings with Varying Search Assets

E. CONTINGENCY OVERVIEW

To complement the MIO concept of operations analysis, a list of contingencies has been gathered. Although the scenarios presented below were not directly analyzed under the modeling portion of the project, we found it necessary to consider them and the contingencies to deal with them. These contingencies represent the boundaries and the rare cases of the problem and help define inherent difficulties in Maritime Intercept Operations. This chapter may form the basis for further exploration or modeling and simulation in future work.

Each contingency is presented with its scenario and the measure taken to mitigate or respond to the situation. The scenarios considered were:

1. Law of the sea violation.
2. Coalition Shifts
3. Unexpected technological threat
4. A/C down / Stranded boarding team
5. Over- success
6. Boarding crew captured
7. Inheritance of Prize Ship
8. Mission aborted (in progress).
9. Medical evacuation
10. Direct Attack

F. CONTINGENCIES

1. Law of the Sea Violation

Although the CONOPS were planned under the constraints of the U.N. Law of the Sea (UNCLOS), it may be possible to present a situation where one of our forces violates international law. This may happen from a navigation mistake, where a unit finds itself in territorial waters instead of international waters, or by a bad decision made by an individual unit commander. A violation of the UNCLOS or any international law could be catastrophic to the mission, causing delays or causing conflict between coastal nations. This contingency requires coordination across the coalition units and amongst unit commanders to execute with precision.

To mitigate this situation, Commanders must be thoroughly briefed and aware of the political situation and sensitivities in their environment. A quick and reliable link to Washington and Coalition / Allied Departments of State must be supported both technically and by procedures, to allow for a quick and efficient high-level response. Also special consideration must be paid to regional states and their sovereignty. Close cooperation between the various Departments of State and regional countries to mitigate and promulgate the latest information on the sovereign territory of the countries in the Area of Operation (AO). Also individual unit commanders, aircraft commanders and Boarding Team Officers must understand the UNCLOS and how it applies to the region. Commanders should spend time and effort during and before operations to train lower level commanders on the UNCLOS and their operational responsibility. It is not enough for only the higher echelon of command to understand these rules since they directly affect commanders, boarding team officers, and pilots during operations.

2. Coalition Shifts

During an especially long MIO operation, the size and composition of the coalition force may vary dramatically. Subject to political stress and interests coalition members may choose to increase, reduce or withdraw the force entirely.

To mitigate coalition shifts, the coalition force must be built in the most modular and interchangeable manner possible. This implies consistent VBSS training for all coalition nations and similar equipment to complete the mission. Furthermore, it is undesirable to rely solely on one coalition member for a particular capability or skill - for example the ability to execute Opposed Boardings. Also each coalition should have the same UNCLOS responsibilities and collective Rules of Engagement to allow the overall commander to utilize standard operating procedures and responses. The overall commander must be responsible for promulgating the correct ROE, UNCLOS guidance, and Pre-Planned Responses (PPRs) to coalition units. Training is also critical to successful completion of coalition operations to keep individual units as standard as possible to afford the commander a degree of flexibility.

3. Unexpected Technological Threat

Experience shows that even when dealing with asymmetrically “weak” adversaries, the other side may surprise by choosing to use high end technology weapons. Consider the use of GPS or communications jammers or Anti-Ship Cruise Missiles (ASCM) during MIO operations (see “Hanit” C-802 ASCM Lebanon incident), and the surprising results to a "superior" force.

To mitigate such an event, proper investment in intelligence must be made, and the task force should be equipped with proper counter measures. Also all assets need to be familiar with PPRs to quickly deal with emerging threats. Lastly the operational commander must develop a coalition information sharing network, so all participating units understand the threat and the best way to neutralize it.

4. Aircraft Down or Stranded Boarding Team

During the course of normal operations in the air and at sea we may lose a vessel or aircraft due to malfunction or enemy action. It is always the originating unit's responsibility to recover its aircraft or boarding team, but other coalition units may be used to help search for and recover critical assets. All commanders need to be prepared to assist any friendly units in distress with current operating forces without creating a dedicated reserve.

For the operational commander a loss of an asset can affect operations in two ways; first the loss of the immediate asset and its crew, secondly the loss of production during the intercept operations. The commander must be prepared to reposition units and assets to prevent the enemy from exploiting the recovery situation, if assets are out of their normal MIO positions. If hostile actions are found to be the cause, the commander also must be able to respond to continue operations and to protect friendly assets in the area who are not capable of self-defense. All units in the operation always maintain the inherent right of Self-Defense and the protection of subordinate small boats and aircraft.

5. Over Success of MIO operations

The main objective of MIO operations is to interdict the transport of illegal weapons, materiel or people. However, based on the experiences of former boarding team members who were interviewed as part of this study, the majority of boarding and searching missions will end with little recovered contraband. A small minority of missions will end with the discovery of some illegal materials or people. Regardless, every unit in the operation should have some ability to detain a few personnel and small amounts of cargo that will be recovered in the normal course of operations.

The situation where a boarding mission leads to the unexpected find of a very large amount of illegal weapons or people is another case for the commander's consideration. In such an event it may be unreasonable for the boarding team to simply seize the materials and leave the vessel, due the weight or quantity of the seizure. Therefore, a reporting procedure and a procedure for returning the vessel to a cooperative port where local law enforcement will take over must be established. This may require the mother ship to escort the target or provide a prize crew to transport the ship to the proper authority.

6. Boarding Team Capture

A boarding crew falling into the hands of the enemy is an unwanted situation which may lead to ransom demands and hostage situations. To reduce the risk of such events, deterrence should be achieved through training of the boarding team in specific combat scenarios and the presence of the mother ship (within line of sight and small arms range) with appropriate crew-serve or small arms weapons ready. The use of aircraft to cover the boarding team when the mother ship cannot observe the entire ship should be a standard operating procedure. The first priority of the mother ship and organic air assets will be to protect the boarding team and be prepared to recover the team at any time. The capture of a boarding team will be dangerous as well as politically and publicly embarrassing for those coalition assets. An example of this hazard is the case of the British Boarding Team captured by Iranian units in the Northern Arabian Gulf in 2005. Boarding teams should be trained to avoid capture and defend themselves, as is within their inherent right of self-defense.

7. Inheritance of Prize Ship

In some cases units may be required to take possession of or escort a target vessel. A vessel could require escort if it has an unusually large amount of contraband or target cargo onboard, or if allied units disable the target vessel during the approach phase of the boarding operations. The commander must work with regional partners to use local assets to tow and assist the damaged vessel, or direct the boarding asset to send a prize crew to take possession of the vessel and take it to the nearest friendly port. The commander should expect all criminals and cargo to be handled by local authorities of either the flag country or local country. If a local country refuses to take the ship it can be transported to the boarding country or destroyed with the permission of the flag state or owner. Numerous previous cases of operations off the coast of Somalia can be used as a template for future operations, where criminals were returned to local authorities for trial and prosecution. The commander must prepare the boarding units to hold prisoners and seized cargo until suitable transportation can be found to a local country for prosecution. Boarding assets should have a pre-designated holding area onboard - whether a formal brig or makeshift shelter – to hold the suspects until the detainees can be transferred to proper authorities. This will require significant cooperation with the U.N. / regional authority and the Department of State of the boarding vessel. These agreements should be in place before or at the beginning of the campaign to prevent political and military embarrassment for coalition nations participating in the Operation.

8. Mission Abort

A need to abort the mission due to new intelligence, unacceptable risk to the boarding crew, supporting air assets, or mother ship may happen at any point in the mission. It is essential to have continuous connectivity to the boarding team, a clear understanding of who has the authority to abort a mission at all levels, and clearly defined abort criteria. The ability to disseminate the cause for the mission abort should be sent to all other coalition units to prevent undue risk to other boarding teams. The individual commanders will always retain Go/No-go criteria for conducting boarding operations. If the commander is uncomfortable with his/her unit's ability to board a suspect vessel, they should contact the overall commander so an appropriate unit can be vectored to support. All coalition units will always retain the right to abort a mission to protect their command and organic assets.

9. Medical Evacuation

A forceful boarding may naturally lead to injury or loss of life. The task force must therefore have appropriate evacuation vehicles and medical support. Either an organic medical detachment or friendly local country should be established for a triage center. Since maritime operations are inherently dangerous, most ships have some variety of medical facilities. If the facilities are unable to handle the specific casualty or volume of causalities, then the commander can route the casualties to the regional medical center. If there is no shore services available the casualty center could also be on a larger asset like a U.S. LHD/A which has hospital capabilities or a local medical center within airlift distance. Friendly medical causalities will be a high priority for the commander's airlift assets.

10. Direct Attack

The CONOPS generally assumes the initiative to engage vessels is the primary mission of the coalition force; however, the enemy may use offensive tactics and attack the MIO task force. The attacks against Iraq's Al Basrah and Khawr Al Amaya Oil Terminals (ABOT and KAAOT) in 2004 provide an example of how the enemy can use MIO operations for offensive tactics. During this operation suspected Al-Qaeda terrorist used a fishing dhow to draw a U.S. boarding team away from the patrol craft and then detonated the dhow as the boarding team approached close aboard. At the time of the explosion high speed boats attacked both terminals simultaneously. Although the small boats did not reach the goal, it proved the ability of terrorist organization to plan and execute maritime attacks with WBIEDs. The use of the WBIEDs on boarding teams can create a distraction and a conflict for the unit commanders. Although the attacks in Iraq were unsuccessful, these scenarios are unsettling for the unit commander who must choose between his/her boarding team and the protected asset.

To mitigate such future events, a high level of readiness must be kept by the task force, intelligence efforts must be made to discover and foil such attempts in advance, and PPRs should be created to allow a quick and effective response. It may be beneficial to explore through modeling and simulation different procedures and techniques for boarding with respect to the possibility of a bombing or attack during the actual boarding.

G. CREATING A COMMON OPERATING PICTURE

The other major function of an operations management group is building a Common Operating Picture (COP) for coalition units and commander to route the proper assets to conduct the mission. The development of a communications network for the quick dissemination of orders, intelligence, and reports is not an easy task, but a task that has been accomplished in the past. The use of systems such as CENTRIX (Combined Enterprise Regional Information Exchange), which allow allied forces to have a dedicated computer network with both voice and data communication is critical for conducting operations. Our group has decided to exploit current technologies such as CENTRIX which has a proven record in exercises and operations around the world, instead of creating new complex large scale communication networks. The problem of communications between mother ship and boarding teams will be discussed in greater detail in later chapters.

H. LAW OF THE SEA AND MARITIME INTERCEPT OPERATIONS

The Law of the Sea is based on the Third United Nations (UN) Conference on the Law of the Sea in 1982 Law and it was eventually signed by 120 countries (the U.S. has signed but it the treaty has not been ratified by Senate). The Law of the Sea establishes a few key concerns for the enforcement of Maritime Interdiction Operations (MIO):

Territorial Sea: Is the ocean extending 12 nautical miles (nm) from the coastal baselines (defined by the treaty), where a country has sovereignty over the sea and air. (UNCLOS, Article 1)

Transit Passage: Is the straits which are used for international navigation between one part of the high seas or an exclusive economic zone and another part of the high seas or an exclusive economic zone. (UNCLOS, Article 38-45)

1. Right of Visit

In the UNCLOS a vessel identified as a warship has the right to visit another ship and verify its flag and documents. Further a warship has the right to conduct a boarding and search for the following considerations:

Right of Visit (Warships) (UNCLOS Article 110)

1. the ship is engaged in piracy
2. the ship is engaged in the slave trade
3. the ship is engaged in unauthorized broadcasting and the flag State of the warship has jurisdiction.
4. the ship is without nationality

5. Though flying a foreign flag or refusing to show its flag, the ship is, in reality, of the same nationality as the warship.

a. Piracy (UNCLOS Article 101)

Piracy is an international crime consisting of illegal acts of violence, detention or depredation committed for private ends by the crew or passengers of a private ship or aircraft in or over international waters against another ship or aircraft or persons and property on board.

b. Slave Trade (UNCLOS Article 99)

The Slave Trade is strictly forbidden on the high seas by the UNCLOS, and any slave seeking refuge is automatically free on the high seas regardless the flag of the vessel providing refuge.

c. Unauthorized Broadcasts (UNCLOS Article 109)

Unauthorized broadcasting involves the transmission of radio or TV signals from a ship intended for receipt by the general public, contrary to international regulation.

d. Vessels without Nationality (UNCLOS Article 110)

Vessels which are not explicitly registered to one particular state are considered state-less and fall under the jurisdiction of all states. Stateless vessels may be boarded in international waters are subject to all law enforcement regulations.

2. Limitations on Law Enforcement in International Waters

Although UNCLOS allows warships to search the ship if the documents or ship's crew arouses suspicion, this does not give warships the right to seize crew or cargo without permission of the Flag State except in circumstances provided in the UNCLOS. Besides the above mentioned reason to board and detain ship, the shipment of illegal narcotics is also specifically mentioned as probable cause to seize a ship under UNCLOS. This limits the scope of MIO without international sanctions or resolutions allowing for the boarding and seizures of ships in a particular area. Since the transportation of weapons and explosives is not inherently illegal on the high seas, for effective MIO for these cargo types a firmer legal ground will need to be established. Cooperation with international governments and organizations is critical to the legal conduct on MIO operations.

3. Other Legal Consideration

a. Piracy

As previously discussed busy international shipping lanes will attract pirates, since the lanes provide targets and camouflage for the pirate crafts. Piracy under international law is applicable only on the High Seas, outside of territorial seas and transit passage waters. Since a ship outside of the high seas (international waters) is committing criminal crimes not covered in UNCLOS, but criminal acts against the State controlling the water. This legal statement provides a need for international cooperation from all littoral states since MIO are conducted in and around territorial seas, and transit passage waters. The benefit to declaring craft as pirates allows any coalition warship to seize the craft and prosecute the crew and vessel under its laws. The difficulty for warships is to establish the crew and/or craft are engaged in piracy.

b. Hot Pursuit

Warships do retain the right of Hot Pursuit under Article 111, but hot pursuit ends if the target ship enters the territorial sea of its State or a third Party State. Any State can prosecute the target ship but a pursing ship must get consent from the flag State or the Third Party State to continue pursuit. Hot pursuit also ends if the ship or aircraft loses the ability to track/see the vessel being pursued. The track can be maintained electronically but must the tracking ship must have continuous coverage. This severely limits the ability of warships in littoral waters to chase and catch ships without complete participation of surrounding states and large sensor network.

3. Conclusions

The legal problems of MIO operations cannot be understated, if we hope to seize cargo, coalition forces must have some cooperation from coastal States in the region to maintain pursuit and limit the ports of refuge for target ships. The necessity to keep all “targets” in track is a key factor is creating a large and robust sensor and communication system that will allow coalition countries to continually maintain contact on target vessels. There is also no convention to stop vessels suspected of carrying WMDs or terrorist supplies without cooperation from the Flagged Country on the High Seas. This factor makes it critical that a commander has the ability to contact host nations or the applicable State Department quickly to conduct effective MIO operations. Lastly the ability of the coalition countries to operate within the bounds of the Law of the Sea is critical in establishing credibility with the international community. The illegal seizures of crew and cargo, even if the cargo is dangerous, will not help future operations since the UNCLOS requires that the sea remain free. The Law of the Sea makes MIO more difficult but conducting legal operations will enhance the coalition credibility. Credible operations, legal seizures of cargo, and prosecution of criminals will act as further deterrence to people who try to exploit the UNCLOS with the intent to harm other nations or people.

V. BOARDING

A. INTRODUCTION

Although the term “Maritime Interdiction Operations” (MIO) is mostly restricted to use by the United States and several close allies, the missions and means to accomplish interdictions in the maritime domain are not limited to those countries. As previously defined, MIO covers a broad range of missions to include everything between sanctions to blockades. While the make-up of each mission is fundamentally the same, the world’s stability can change at a given moment forcing the mission of a particular asset to be refocused to respond. Based on the number and type of assets available, a mission planner can address the current focus and adapt his forces to address the shift in missions. Chapter V. is focused on boarding the target vessel.

Understanding the objectives of the mission as well as the capabilities and limitations of the targeted vessel is an important top-level consideration in planning a MIO. The MIO concept is broad ranging and can present complex scenarios that could prove to be economically inconvenient, culturally antagonistic, and even deadly if the risk is miscalculated and appropriate mitigating actions are not taken.

As discussed in the CONOPS, boarding teams must be able to conduct simple boarding missions of compliant vessels and also be ready to confront an opposed target should the scenario present itself. In considering all levels of boarding missions, we found there are certain force platforms and countries incapable of handling certain types of MIOs. One of the reasons is these platforms cannot support the tools necessary to conduct such missions.

B. PHASE SHAPING

While defining the parameters of MIO missions, boarding a target vessel is not always required in order to interdict a vessel. A vessel could satisfactorily pass the initial verbal query via bridge to bridge radio and be cleared to proceed. If a vessel is thought to be carrying illicit cargo, the interdicting force may be required to put personnel onboard to conduct a search. The nature and scope of the boarding will vary depending on the level of compliance of the suspect vessel – these boardings designated by the Phase level.

During Phase Zero and Phase One, US forces will provide the leadership and guidelines in conducting all MIO missions in a US specific Area of Operation (AOR), assuming there is no fundamental change in the US' military policy in the timeframe of interest. When Phase Two is being conducted, the option to incorporate Allied Forces into the overall operation becomes available.

The inclusion of Allied Forces into Phase Two Operations generates a need to thoroughly understand allied assets to facilitate the buildup of different force structures best suited to handle MIO missions. The characteristics that each asset contributes to MIO missions can be evaluated and compared through a pair wise comparison using an optimizing Excel model. This model was based on a fixed set of variables that results in an optimal mixture of assets and force packages that were made up of both US and foreign ships.

In order to create a realistic force structure, we investigated multiple classes of ships to determine which mixes could be used in various types of MIO missions. This analysis is designed to accurately reflect the vast differences in ship classes used throughout the world today. The purpose of looking at many classes of ships was to avoid the exclusion of a MIO capable platform that could prove viable in joint operations.

C. SCOPE OF PAIR-WISE COMPARISON

The scope for this analysis was narrowed to countries currently engaged in some form of MIO missions, as well as countries that would “most-likely-assist” in a combined mission. The following seventeen nations (NATO members and several Allies from the Asian region) were chosen for evaluation:

Canada	Portugal	Spain
Australia	Greece	United States
Turkey	Pakistan	United Kingdom
France	Germany	Taiwan
Philippines	Singapore	Denmark
Indonesia	Italy	

One hundred and eight different MIO capable ship platforms were considered and evaluated. The individual platforms were ranked and sorted in order to show relative capabilities between the assets which can then be translated into optimal force packages to address the mission at hand.

D. PAIR-WISE COMPARISON CHARACTERISTICS

To fairly assess each country’s MIO assets, a set of characteristics that contribute to each type of mission were identified and weighted according to the assets’ overall contribution to conduct MIOs. The resulting score was a subjective rating of the overall effectiveness in contributing to MIO missions. The minimum score was one and the maximum score for each characteristic was 10. This rating determined the weight each characteristic would have in the model as each ship was evaluated. When added together, the percentages of each attribute summed to 100% of the weighting criteria.

In order to define a set of characteristics that apply to the boarding process it was essential to look at the key components of the boarding process.

These components were taken from the functional decomposition of the term 'To Board', located in Appendix B. Should there be a MIO mission that is tailored to requirements that differ from that assumed for this report; the weights can be modified to reflect the appropriate change of importance. The "overall effectiveness" of a ship was defined as the ships' ability and proficiency to perform the following 10 tasks:

1. Possession of disabling organic armaments
2. Crew number that sufficiently supports the boarding process while maintaining ship operations
3. Number of equally effective boarding teams available
4. Capability to accelerate from dead in the water to full speed in order to pursue non-compliant vessels and to respond with emergency support to the boarding team(s)
5. An ability to attain and maintain the maximum speed
6. Number of helicopter and their capabilities
7. Type of helicopters that can land on the asset's flight deck
8. Rigid Hull Inflatable Boat (RHIB or small boat equivalent) capabilities
9. Unmanned Arial Vehicle capable (UAV)
10. Unmanned Surface Vehicle capable (USV)

Each of these categories was given a subjective weight based on a poll of subject matter experts working on this report. The weights are meaningless in terms of a quantifiable linkage to a real world number, however they are reflective of the importance assigned by the analysts creating this document. The general logic and reasoning behind each of the criteria weights are assigned below.

The first characteristic chosen was organic firepower provided by the mother ship of the boarding team. A ship's weapon can provide a deterrence that helps to ensure the boarded ship remains compliant throughout the boarding process. Furthermore, the ship's organic weapons provide a deterrence against outside factors that may attack the boarding team. Since the organic weapon may or may not have a direct effect on the boarding itself, the weight of this characteristic was given 5 out of the possible 10. This score resulted in giving organic firepower an overall weight of 6% in the model.

The second characteristic evaluated was the number of the crew of each ship. The number of crew generates a potential pool to create additional boarding teams leaving a higher importance in the boarding process. If a ship complement is 45 personnel, the ability to comprise two properly trained and physically fit boarding teams while maintaining properly manned watch stations in day to day operations is not as practical as choosing from a crew of 100 or 200 sailors. This characteristic does not take into account the ability of a ship to carry an additional complement of personnel who solely deal with MIO. The results of this aspect would only further cater to the larger vessels as they maintain a greater ability to host such detachments. Due to the direct effect on the boarding process; this characteristic was given 9 out of the possible 10. This score resulted in giving crew size an overall weight of 12% in the model.

The third characteristic evaluated was the number of boarding teams each ship can maintain. The greater number of boarding teams a ship can maintain, the more consecutive MIOs can be performed. This approach addresses issues such as crew rest, crew replacement in the event of a personnel casualty, and the ability to search larger vessels if called to do so. Although two boarding teams are sufficient to conduct boarding operations on a vessel less than 300 tons, substantially larger vessels still need to be considered. The number of teams available at any given time for a MIO mission provides flexibility to the MIO mission planner so its weight was considered to be higher in the scale. Again due to the direct effect on the boarding process, this characteristic was given a 9 out of the possible 10. This score gave the number of boarding teams each ship could maintain an overall weight of 12% in the model.

The fourth and fifth characteristics pertained to the speed of the mother ship. If the suspect ship decided to risk making an escape from the area to avoid being detained, the mother ship would need to intercept the fleeing ship. Speed is also important if the mother ship must quickly come close to the boarded ship to provide emergency support to the boarding team. These two scenarios established a need to evaluate the number of engines as well as the propulsive output of each asset, given that the U.S. Navy operates in a logistically barren environment. Since speed plays a higher support role for MIO, it scored an 8 of 10 resulting in an overall weight of 10% in the model. The overall speed of the asset and total number of engines were assigned an overall weight of 6% apiece in the model.

The sixth characteristic evaluated was the total number of helicopters and their capabilities available to each ship. This characteristic directly affects a ship's ability to conduct vital parts of MIO missions, from surveillance to providing support in both search and rescue missions as well as providing cover for boarding teams that are embarking and disembarking from the suspect vessel. Another aspect of platforms that carry helicopters is the additional capability of making an airborne insertion and extraction of boarding teams. Although the Helicopter Visit Board Search and Seizure (HVBSS) capability is rarely conducted, it is a capability that cannot be ignored as there is a probability that an HVBSS may be required. With this in mind, each additional helicopter increases capabilities in the amount of area under surveillance, hostile force identification, and the ability to maintain an air presence in the event of helicopter unavailability (e.g., maintenance). The characteristic of the number of helicopters focuses on the overall carrying capacity of helicopters. A consideration that adds to the importance of a platform's helicopter capability is the ability to provide fuel and maintenance to "visiting" aircraft from other ships. The characteristic of the number of helicopters scored 8 out of a possible 10 resulting in an overall weight of 10% in the model.

The seventh characteristic is the type of helicopter that can be supported and is on board each ship. Certain helicopter platforms provide other than MIO mission capability but add flexibility in the types of support for the boarding process. The ability to carry and maintain a multiple mission capable helicopter received a 7 out of a possible 10, resulting in an overall weight of 9% in the model.

The eighth characteristic in the boarding process is the number of Rigid Hull Inflatable Boats (RHIB's) organic to the mother ship. This characteristic directly affects MIO missions based on the number of teams in RHIBs a ship can have in the water at any given time. The total number of RHIB's carried by a platform influences the amount of equipment and boarding teams that can be transported in one movement. Similar in weight to the number of boarding teams, the number of RHIB's also scored 9 out of a possible 10 for a total weight of 12% in the model.

The final two characteristics examined were for capabilities for accommodating Unmanned Arial Vehicles (UAVs) and Unmanned Surface Vehicles (USVs). These traits carried the same weighted. The measure considered was whether or not the platform could carry and employ the capability in the future vice if the platform currently maintained this capability. This determination is based on on whether the platform could support the landing of a helicopter onboard, and separately, if it could carry and launch a small boat. The unmanned vehicle capability is being considered by the Navy for unmanned aircraft and surface vessels. Both of these characteristics were weighted a 9 out of a possible 10. Both characteristics accounted for a total of 24% of the total weight in the model, 12% for USV capability and 12% for UAVs.

The combined breakdown of characteristics as a percentage of importance is provided in Figure 7.

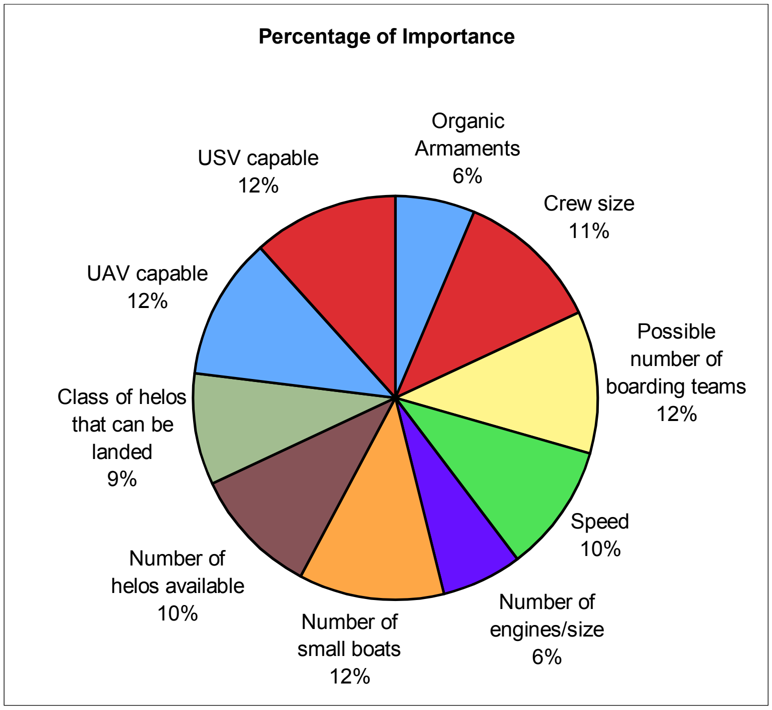


Figure 7: Percentage Breakdown of Importance

E. RESULTS OF PAIR-WISE COMPARISON

The complete results from the pair-wise comparison of all ships are provided in Appendix D. The top ten contenders, arrived by this method, are shown in Table 5. The multi-million dollar Tarawa Class LHA, which can carry a small city and provide enough logistic support to complete any MIO mission, shows up at the top of the results. This creates a need to measure the platforms against each other without using cost as a baseline.

The factors studied in this pair-wise comparison are not exhaustive nor universally complete. They are representative of the most general conditions of doing a MIO as is derived in the scoping of this project detailed in chapter one. Different MIO missions are impacted by factors other than listed in this analysis that can drastically sway a platforms ability to utilize its capability. An example of not being able to use capability is displayed in Figure 8. This photo depicts the

Essex Expeditionary Strike Group participating in an exercise with the Philippine Navy in early 2006 which operated with the two smaller San Juan class Frigates. From Table 6, the San Juan class came to have the lowest rating in the comparison model. However, in the event that a MIO was necessary, only the San Juan class ships would likely be able to conduct that operation legally in Philippine territorial waters. The San Juan class scenario depicts the fact that the perceived perfect fit to a scenario will not always be the proper asset needed for mission success.

Single Ship Results 1-10	
Tarawa class (LHA)	9.05
LHA 6 class	9.01
Wasp class (LHD)	8.95
Ticonderoga class cruisers (US)	8.88
Arleigh Burke class (US)	8.88
Keelung (Kidd) class (Taiwan)	8.85
Spruance class (US)	8.82
San Antonio class	8.74
Austin class (LPD)	8.56
De la Penne (Italy)	8.53

Table 5: Single Top 10 Ship Results

Single Ship Results 99 -108	
Roussen (Super Vita) class (Greece)	2.47
Larkana (Pakistan)	2.29
Jalalat (Pakistan)	2.23
Auk class (Philippines)	2.21
Sea wolf class (Fast Attack Craft) (Singapore)	2.17
Rafael Protector Unmanned Surface Vehicles (Singapore)	2.17
Rajshahi (Town class) (Pakistan)	2.05
Tomas Batilo (Sea Dolphin) class (Philippines)	1.79
Cyclone class (Coastal Patrol ship) (Philippines)	1.67
San Juan Class (Philippines)	1.29

Table 6: Single Bottom 10 Ship Results

Figure 8: USS Essex ESG with San Juan Class Ships

F. OPTIMIZATION OF FORCE STRUCTURES THROUGH CHARACTERISTICS

While attempting to compare US forces with that of ally nations, three of the ten characteristics were selected for each force package scenario. The three characteristics listed below allowed a common metric to be evaluated across different force structures and MIO missions:

-The size of the crew (Manpower)

-The number of helicopters deployed

-The number of RHIBs for boarding.

1. Baseline Force Package Composition

Excel's solver was run several times to find optimum force packages from a set of constraints that will be discussed in detail later in this chapter. Each run was based on one factor that remained constant in order to provide results that could be compared with a baseline.

In an effort to build hypothetical coalition force packages, three separate US Expeditionary Strike Group force packages were created and used as a baseline for comparison. The purpose for using three separate force packages is to represent different Expeditionary Strike Group (ESG) force compositions. MIO can be conducted with a variety of assets; however this analysis only looked at common force packages as they pertain to the US military at the time of the writing of this report. The assets that best support this type of scenario are the US ESGs as they maintain an ability to carry out extended independent operations and can provide a comprehensive logistics support chain. An ESG has many compositions as its base structure consists of a three ship Amphibious Readiness Group (ARG) with a two to three ship addition that provides support in the form of, but not limited to any of the following: cruisers (CG), destroyers (DDG), and frigates (FFG). The compositions of each ESG will be determined from what missions will be performed during an underway period and what assets will be available for use by the date of said underway.

<u>Force Package 1</u> consisted of:

-1 Tarawa class LHA (Landing Helicopter Assault)

-1 Whidbey Island class LSD (Dock Landing Ship)

-1 Austin class LPD (Amphibious Transport Dock)

-1 Ticonderoga class CG (Guided Missile Cruiser)

-1 Arleigh Burke class DDG (Guided Missile Destroyer)

Force Package 1's characteristics consisted of the following:

-4143 personnel underway on 6 ships

-31 helicopters

-17 RHIBs

<u>Force Package 2</u> consisted of:

-1 Wasp class LHD (Landing Helicopter Dock)

-1 Whidbey Island class LSD

-1 Austin class LPD

-1 Oliver Hazard Perry FFG (Guided Missile Frigate)

-2 Arleigh Burke class DDG

Force Package 2's characteristics consisted of the following:

-4218 personnel underway on 6 ships

-31 helicopters

-17 RHIBs

Force Package 3 consisted of:

-1 Wasp class LHD

-1 Whidbey Island class LSD

-1 Austin class LPD

-1 Oliver Hazard Perry FFG

-1 Arleigh Burke class DDG

Force Package 3's characteristics consisted of the following:

-3856 personnel underway on 5 ships

-29 helicopters

-15 RHIBs

2. Force Package Effectiveness

The effectiveness of each force package was determined for comparison against the Excel solver's results. The comparable score is used to provide a weighted value that can be used to determine if the alternative results are either better or worse than the baseline force packages. The effectiveness scores of the force packages were:

Force Package 1: 86.4% (average); 5.18 (comparable score)

Force Package 2: 86.2% (average); 5.17 (comparable score)

Force Package 3: 85.7% (average); 4.29 (comparable score)

Further breakdown of results can be found in Appendices E, F, and G.

Once the effectiveness of the each baseline force package was determined, it was discovered solver would then comprise force packages that were unrealistic so several constraints were placed on the model. One constraint that was placed on the model was that Excel was not able to select more than 2 of any certain class type of ships. This provided a more realistic result and a more diverse mixture of ships. Another limiting factor that was imposed onto the model was that during the analysis of the variables of the number of helicopters and RHIB's, platforms that did not have either capability were removed from the selection pool. This eliminated the unfair advantage that Excel would select these platforms since it did not affect the overall "cost" restriction of limiting the number of helicopters and RHIBS available.

Another restriction that was placed on the model during each scenario was that the selection of platforms was limited to no more than 10 ships. The scenario was run for 6 ships, 8 ships, 10 ships, and 12 ships. It was found that the effectiveness was not significantly altered nor did the force composition change dramatically from the predetermined baselines. A 10 ship constraint was the next number of ships chosen and showed a more significant difference in terms of both effectiveness and ship composition. A 10 ship package was chosen for further analysis because it allows for the creation of two 5 ship Surface Action Groups (SAGs), which would present a more manageable command and control structure during the operation.

The sum effectiveness of each package's run (or comparable score) shows how much effectiveness is brought to the MIO area from each package. The comparable scores allow each result to be normalized for an equal comparison to each other. With the restriction that all mother ships must be with 8 nautical miles of the boarded ship during a boarding, the higher the comparable score the more desirable the package is. The higher score allows more ships to operate in an area which in turn allows for more boardings to be conducted at any given moment.

G. FORCE PACKAGE MODEL RESULTS

1. Manpower Scenario

During the first scenario, Excel Optimizer was limited to the maximum personnel per force package for each run. The results from the first run provided an alternative force package of 78 ships with a total crew size of 4143 and an effectiveness average of 46.1%. The reason that the average effectiveness decreased while the amount of ships increased was due to Excel's selection of ships. Excel chose the ships with low effectiveness because it was able to add more ships to the total count while still remaining with the restraint of 4143 personnel. Although the result may appear that the original force package performed better, the comparable score for the alternative was 6.9 times better. The comparable score for force package 1 was 5.18 (.864 effectiveness * 6 ships = 5.18) while the comparable score for the alternative force package was 35.96 (.461 effectiveness * 78 ships = 35.96). This result shows that the alternative force package 1 is almost 6 times a better selection. With more ships in a given area, MIO boarding operations effectiveness can be increased. When the 10 ship selection constraint was placed on the model, the resulting average effectiveness was 87.1%. The comparable score achieved was 8.71, which performed 1.7 times better than the baseline effectiveness.

The second and third run produced similar results when the personnel limit was set to 4218 and 3856, respectfully, with only a few exceptions. During the second run the recommended alternative force package contained 81 ships while the third run's alternative force package consisted of 75 ships. Alternative force package 2 scored a 44.8% average effectiveness while alternative force package 3 had average effectiveness of 45.6%. When the comparable scores of the alternative force packages were weighted against the baselines, the alternative packages performed close to 7 times better. Once the 10 ship constraint was placed on run two, the resulting average effectiveness was 87.5% and received a comparable score of 8.75, which again performed 1.7 times more effective than the baseline package.

Although the 6 ship baseline's average effectiveness was higher then the 78 ship alternative and the 10 ship configuration but by looking at the sum of the effectiveness each package presents, an equal comparison can be achieved. In this arena, the 78 ship alternative excels over both the 6 and 10 configurations because there are more ships operating in a MIO area. The similar results occurred during the second and third run of the model which coincides with the results of the first run although the force packages of alternative 2 and 3 were different. This trend in the results continues in each run and alternative force package configuration.

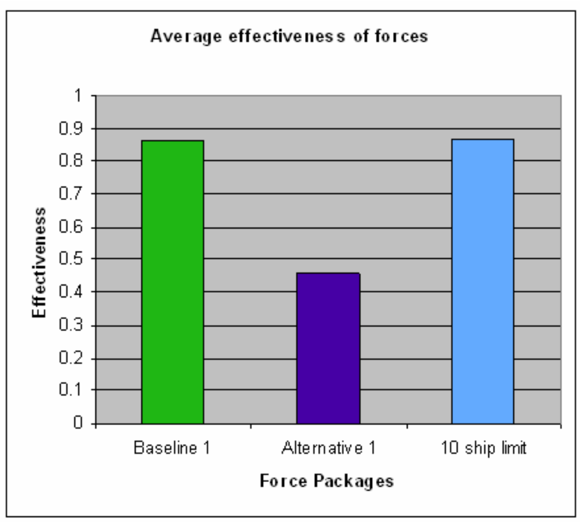


Figure 9: Effectiveness with Manpower

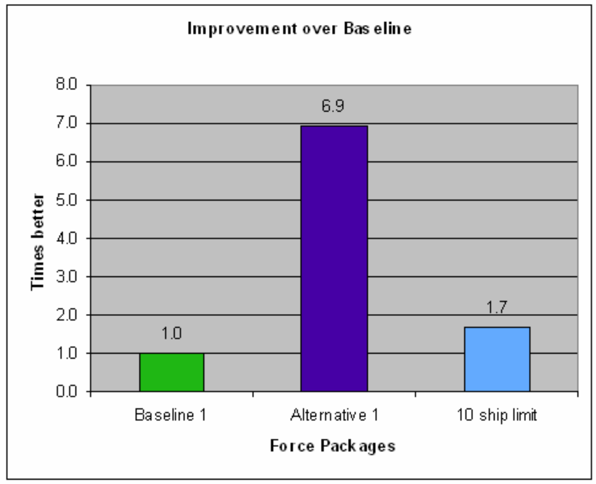


Figure 10: Improvement over Baseline

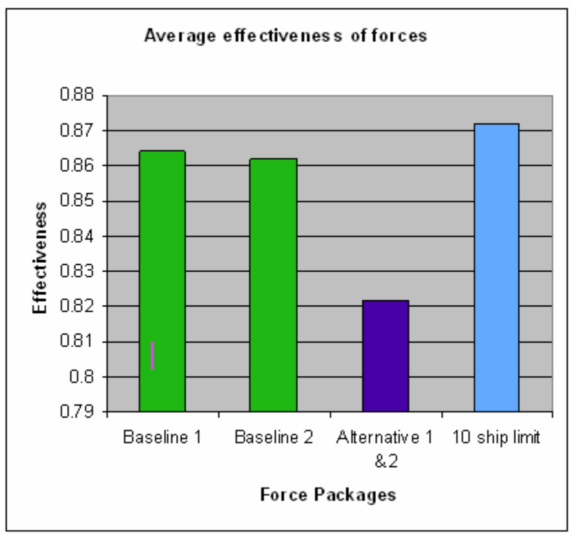


Figure 11: Effectiveness with Manpower

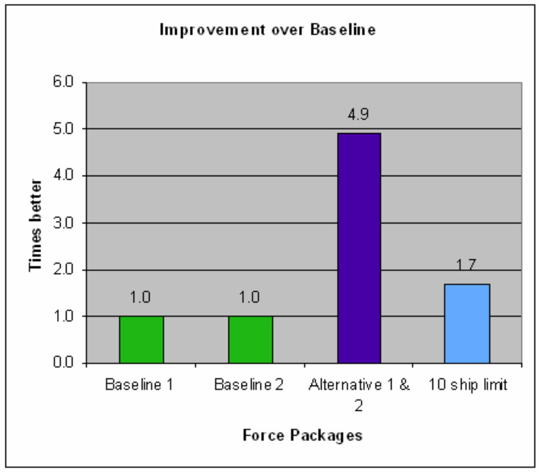


Figure 12: Improvement over Baseline

2. Helicopter Scenario

The second scenario that was created for the model was to find an alternative force package using the number of helicopters that are provided by each baseline package. Once again, the comparison results were consolidated since baseline package 1 and 2 contained a combined number of 31 helicopters and baseline package 3 held 29 helicopters. The result of the model's optimization was an alternative force package of 31 ships for both the first and second run; the third run resulted in a package of 29 ships. The average effectiveness for the alternative force package was 82.2% and a comparable score of 25.48 for runs one and two. The third run received an average effectiveness of 82.4% and comparable score of 23.9. The comparable score shows that the alternative force package compared to baseline package 1 and 2 was almost 5 times more effective then the baseline package and 5.6 times better then baseline package 3. The result of the 10 ships constraint force package was an average effectiveness of 87.2% and a comparable score of 8.72 which was 1.7 times as effective as baseline package 1 and 2. When alternative force package 3 was constrained to 10 ships, the resulting effectiveness was 85.1% which produced a comparable score (8.51), almost twice as better as the baseline package.

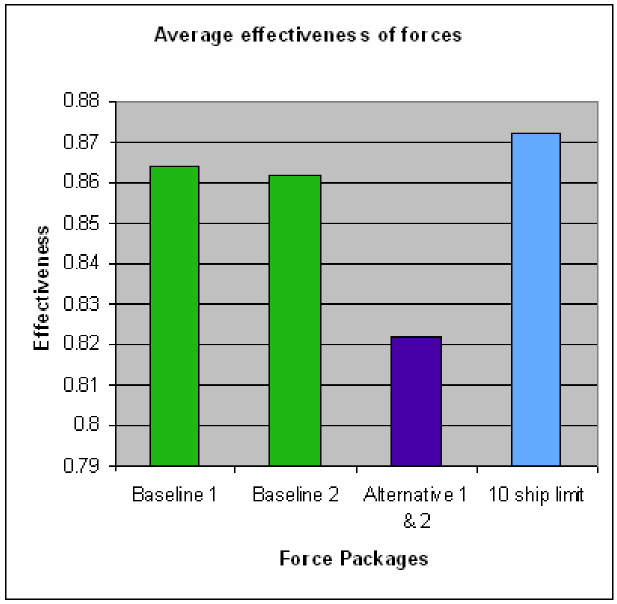


Figure 13: Effectiveness using Helicopters

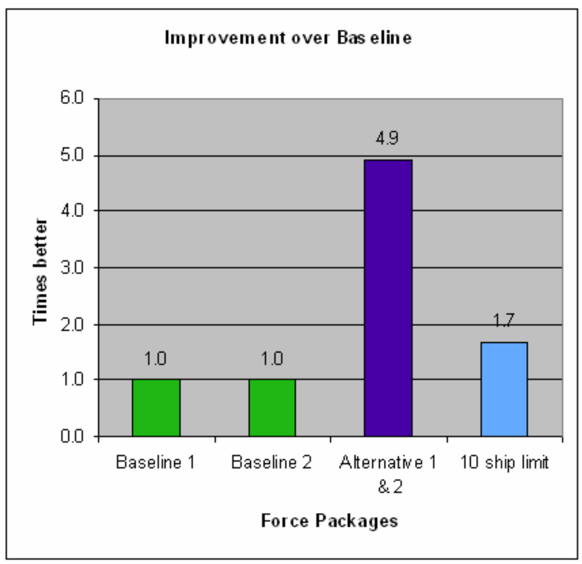


Figure 14: Improvement over Baseline

3. Rigid Hull Inflatable Boat Scenario

The third scenario limited the model by the number of RHIBS that were provided by each baseline package. As before, the number of RHIBS that were available for baseline package 1 and 2 were identical (17 RHIBS) resulting in the exact alternative force package. The alternative force package of 17 ships received an average effectiveness of 81.7% and a comparable score of 13.89. The outcome of the model produced alternative force package that was over 2.6 times more effective then baseline package 1 or 2. Once the 10 ship constraint was placed onto the model run, the result was an alternative force package with an average effectiveness of 87.3% and a comparable score that was 1.7 times (8.73) more effective. During the third run of the model, the limiting factor was changed to 15 RHIBS, which was the normal load out of baseline package 3. The resulting alternative force package was 15 ships with an average effectiveness of 82% and a comparable score of 12.3 which is almost 3 times more effective then the baseline package. During the model run with a 10 ship constraint, the resulting alternative force package had an average effectiveness of 86.3% and a comparable score of 8.63 which was a little over twice as effective as the baseline package.

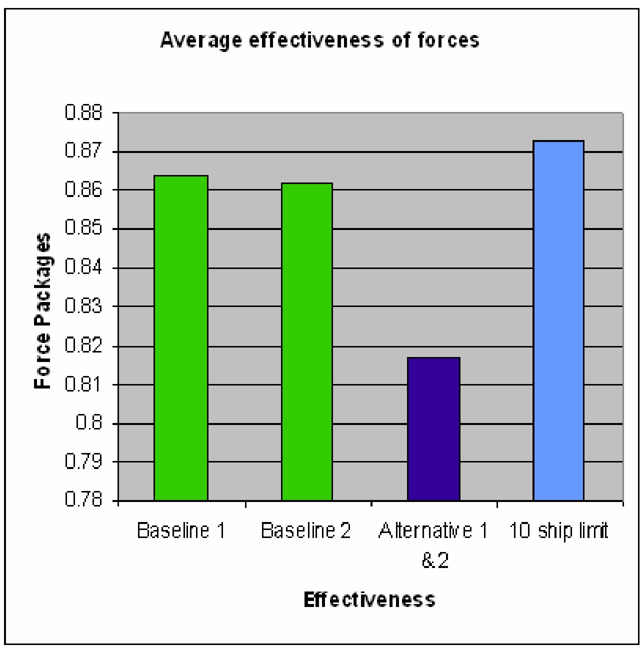


Figure 15: Effectiveness with RHIB's

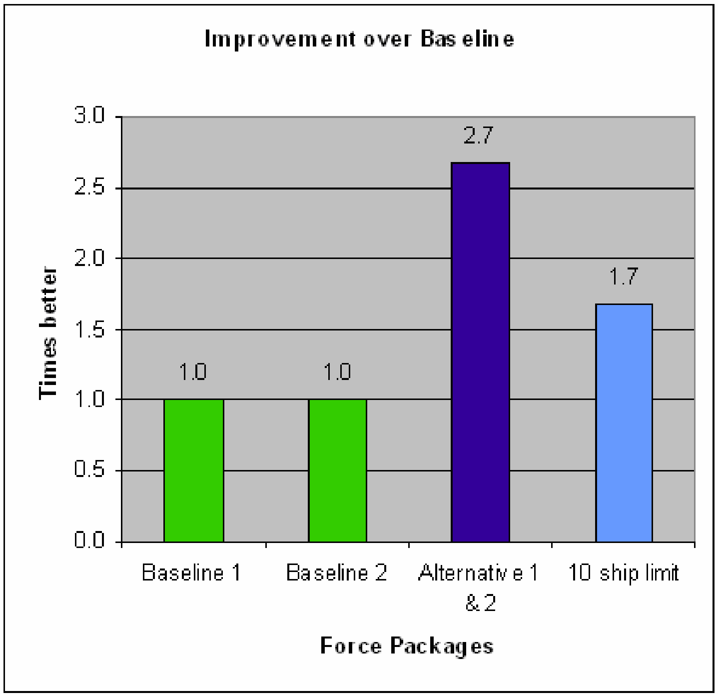


Figure 16: Improvement over Baseline

H. RESULTS AND MODEL CONCLUSION

The results from all of the scenarios' runs indicate the alternative force packages resulted in a more effective MIO structure than the current baseline of 5 and 6 ship ESG composed of US LHAs, LPDs, LSDs, DDGs, CGs and FFGs. By analyzing the different variables and factors that are associated with each class of ship, the Excel Optimizer showed that given more ships operating within a certain area, a more thorough MIO operation can be conducted while not losing assets' time patrolling on station. With the limiting visual range constraint to the boarded ship, at any given time there can only be (at most) 6 boardings occurring at any moment given the baseline packages, while the alternative force packages allows for a substantial amount of boarding operations depending on the configuration used.

Another result from the Excel Optimizer model was to show that of all the platforms viewed, a high-ranked lone American ship was more effective then any other lone allied country's ship. This shows that if only the weighing factors, that were used at the beginning of the model, were analyzed almost any US ship can out-perform the MIO capabilities of an allied force. Ultimately the proper force package that would be recommended depends on the over arching MIO mission and the allied force assets. If the goal is to conduct as many MIO boardings as possible given a certain volume of shipping traffic, any alternative force package that was created from the model could be utilized depending on which limiting factors are used (manpower, helicopters or RHIB's). If the goal is to have a limited number of ships conducting MIOs that are unobtrusive and result in minimal delays, then either the original baseline force package or the 10 ship alternative would be ideal. Another reason that the 10 ship configuration was more ideal then the more ship intensive alternative packages, was because of the logistical chain that would be needed to support the ships. As defined in Chapter 1, section C, paragraph 4, the area of operation is logistically barren which would not allow the robust alternative packages to efficiently operate without large logistical chains in place. The reason that fewer ships operating in an area would be ideal is not only the logistical barren aspect but also the sear congestion that would occur in a small operating box packed with many allied ships. The only limiting factor in determining an ideal force package would be the goal trying to be achieved. If the MIO mission was to conduct a boarding on every ship passing through an area then the only realistic force package would be to a more robust package then the one presently being used. If the mission is to conduct a random amount of boardings or intel only boardings, then the present day package or the 10 ship package can be made use of.

I. HELICOPTER VISIT BOARD SEARCH AND SEIZURE

HVBSS is a MIO mission capability with which many people are unfamiliar. The HVBSS mission is generally passed over due to the equipment needed to perform this mission, familiarity of the methods of insertion and extraction, and the physical capabilities of the boarding team members. Not every boarding team member is capable of this method of boarding and this places one more constraint on the pool of manpower a mission planner can draw from to form the desired boarding and support teams. The HVBSS mission is only being taught in boarding schools to specific teams. It is not a capability inherent to all VBSS teams which is why it would put another constraint on the pool of people to be drawn. It is a characteristic that is under accounted for due to the fact not all boarding teams have this capability. The capability was accounted for in terms of the helicopter capabilities. Another key factor that affects current boarding team capabilities is the boarding team needs to function independently from the mother ship if they become cut off from all communications for tactically significant length of time. Previously, HVBSS capabilities were limited to the Special Operations Forces of the various services due to their expertise and ability to carry out mission objectives independently and are now slowly being integrated into HVBSS teams throughout the fleet.

HVBSS based MIO offers several advantages over waterborne MIO. HVBSS can be conducted independent of sea state, at greater ranges, and may support operations on multiple targets. An opposed boarding conducted from a helicopter can be considered more safe than a waterborne MIO as there is no requirement for boarding team members to physically jump between vessels or to climb high freeboards starting from sea level. However, during an HVBSS there are more ways in which to lose the entire team based on aircraft failure or the aircraft's susceptibility to small arms fire and anti-aircraft weapons than waterborne operations. HVBSS's are still safer than waterborne MIOs in level four boarding conditions as the helo has the ability to apply suppressing fire against the target ship's crew before, during and after the boarding team rappels on to the target ship without requiring a risky jump (which may be one boarding team member a time) or a slow climb up a high freeboard.

The relative speed for which a boarding team can move from the parent ship to the target ship may give some advantage to HVBSS in the event that the target ship is capable of great speeds. When there is a requirement to carry multiple boarding teams additional helicopters will be needed. The use of multiple helicopters will provide additional de facto ISR assets. One asset examined in the force structure portion was the Jeanne de Arc Helicopter carrier from France. This asset was weighted highly in this area and could provide adequate support in the form of number of helicopters as well as the logistics to sustain a helicopter force.

The basic premise behind conducting an HVBSS is a ship with a multitude of helicopters and boarding teams enters an area and searches merchant ships for illicit cargo. Boarding team members with all of their search equipment will repel out of the helicopter onto the target vessel and proceed to search the target ship. Following the completion of the search, the boarding team will need to return to the parent ship. Assuming the target vessel does not assist in the transit back to the originating ship, the helicopter will be required to move the boarding team to the mother ship.

Communications within the boarding team will be very difficult in the HVBSS environment (without having the parent ship near by). Though a helicopter can be used as a relay, the probability it would be at a sufficient altitude to perform this function is improbable and may result in intermittent and unreliable connection. In order to ensure that communications with the boarding team remain constant, a dedicated airborne relay may be required. Alternatively, the boarding teams could potentially relay messages through a communications satellite should an airborne relay not be available. The situation where the parent ship would not be within line of sight refers to situations where helicopters are being used to do MIO’s with multiple boarding teams on multiple geographically dispersed targets.

The HVBSS capability is being explored and perfected by boarding teams during current naval exercises. HVBSS-1 is an example of such a team. It was stood up in February of 2007 as part of the Navy Expeditionary Combat Command and conducted training in the USS Abraham Lincoln Strike Group’s

(CVN 72, CSG-9) Composite Training Unit Exercise (COMTUEX).[7] At least three equivalently trained and equipped teams are expected to be stood up and stationed on each coast of the U.S. which makes this capability more of a commonplace asset by 2013 vice once solely reserved for the SOF.

J. RECOVERY

Recovery of the boarding team will occur when the search of the target vessel has been completed to the satisfaction of the boarding officer's and a higher authority clears the vessel to proceed, or if the mission is aborted. At any time during the boarding process the mother ship or fellow boarding teams may determine that it is necessary to exit the suspect vessel.

Prior to making the recovery of the boarding team one key assumption is made and it places the boarding team in a very vulnerable position. The crew of the boarded vessel, whether compliant or non-compliant prior to boarding, has been pacified and poses no threat to the boarding team during the team's extraction and recovery. These assumptions will hold true for future MIO operations, because it is expected that commanders will not needlessly expose boarding teams to excessive risk. In many cases where there is blatant hostility and weapons' fire from a target vessel, the mission would most likely be transferred to a special operations team to execute.

During the actual recovery process it is expected that weapons from a supporting helicopter or supporting RHIB will provide protection and covering fire if necessary for the boarding team members as they depart the vessel. The recovery process leaves some members of the boarding team in an extremely vulnerable position. This is the one instance a boarding team member has his back to the vessel's occupants. As long as there is a deterrent force present the vessel's occupants may not be tempted to inflict hard force on the exiting team

7 ''Unexpected Company' arrives for COMTUEX' by MC3 James Evans on November 2, 2007. Last accessed 28 May 2008 on webpage: http://www.northwestnavigator.com/index.php/navigator/region/unexpected_company_arrives_for_comtuex/.

member. The supporting helicopter or RHIB may be too distant to provide a rapid deterrent response to an attack on the last departing team member. It is recommended that future projects consider the development of a deterrent system such as a small, hovering UAV that could be positioned closely to the point of exit.

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VI. SEARCH

A. INTRODUCTION

After boarding and securing the suspect vessel, the next step, which is also the objective of many Maritime Interdiction Operations (MIOs), is to search the ship for illicit cargos. This function is conducted by the sweep team of the boarding team.

As mentioned earlier, four types of illicit cargos that are targeted, i.e., smuggled humans/animals, illicit narcotics, firearms like guns and mortars, and explosives. It is very likely that the cargoes will be hidden.

1. Aim

The aim of this chapter is to study how one can find and identify targeted cargos more effectively. Effectiveness is increased by cutting down search time and increasing the probability of detection. Since the solution needs to be fielded by 2013-2014 timeframe, any search equipment proposed need to be based on current technology.

B. APPROACH

The approach adopted for the study was based mainly on Systems Engineering Methodology. The problem was first identified and studied. Types of cargos to be searched were identified while constraints were placed upon possible solutions. A functional decomposition of “to search the suspect vessel” was performed in order to understand what functions are required for the search. With the functional breakdown, measurements of effectiveness (MOE) were next identified in order to determine how well the recommendations were as compared to what is being used now.

A market survey of commercially available products was conducted to identify possible technologies and equipment that can be used to search for the targeted cargos. The effectiveness of each type of equipment was then measured in computer models. The equipment set that improves over the current practices is recommended.

The study concludes with a recommendation regarding MIO effecting technologies worthy of further investigation.

C. CURRENT PRACTICE OF SEARCH

Before a set of recommendations can be derived, a better understanding of the current baseline is required. The baseline used for this study is the current methodology employed at the time of the writing of this report.

Currently, once the suspect vessel is boarded and secured, the boarding team will be split into a security team and a sweep team as has been predetermined... The Boarding Officer will determine the type of search or sweep to be conducted based upon previous intelligence, inspection of the suspect vessel's documentation, and OPTASK guidance[8]. Under orders of the Boarding Officer, the sweep team will then sweep the ship and its cargos visually. Equipment used by the sweep team includes bolt cutters, wire cutters, pry bar, sounding tape, thief sampler, inspection mirror and flashlight. The primary mean of detecting, identifying and classifying any targeted cargo is through the searchers' eyes. In order to find a hidden targeted cargo, the sweep team usually will need to open a suspected container by using a pry bar or cutter. The entire search process is inefficient and usually takes a long time, exposing the boarding team to danger for an extended amount of time.

[8] "NTTP 3-07.11 Maritime Interdiction Operations", E.d. Nov 2003, published by U.S. Navy.

D. PROBLEM DEFINITION AND CONSTRAINTS

The baseline for comparison is the current practice of search. The targeted cargo can be classified broadly into four categories:

1. Smuggled humans or animals
2. Illicit narcotics
3. Firearms (e.g. guns and mortars)
4. Explosives

Constraints identified for the study include:

1. Cargos are hidden.
2. As most, if not all, ships are made mainly of metal, the sensing equipment used to search the ships need to either "see" through walls or detect traces of the targeted cargo outside the walls.
3. The chosen equipment, ideally, has to be able to be brought onboard the suspect vessel. Therefore the equipment cannot be too bulky nor too heavy. If it is to be "piggy-backed" by the boarding team, it should be twenty lbs or less.

E. FUNCTIONAL DECOMPOSITION

The function of "To search the suspect vessel" was decomposed into its sub-functions for us to understand what is required for the search. The functional decomposition is as shown in Table 7.

6.0 To search the suspect vessel
- 6.1 Determine search methodology (exhaustive, random or targeted)
- 6.2 Determine search target set (weapons, narcotics, people, etc)
- 6.3 Determine needed asset mix to search a ship
  - 6.3.1 Determine number of people needed

6.3.2 Determine amount of time given to search
6.4 Transport search equipment to or from the parent ship and suspect vessel
6.5 Search the ship
6.5.1 Detect suspected target cargo
6.5.2 Identify targeted cargo
6.5.3 Classify targeted cargo

Table 7: Functional Decomposition of "To search the ship"

As can be seen in Table 7, to search the suspect vessel requires the search methodology to be determined first, followed by determining the target set. Knowing beforehand the likely target the sweep team will be looking for will help to determine the type of equipment the team will be bringing onboard the suspect vessel. This is followed by determining the needed asset mix to search the ship and transporting these assets to the suspect vessel. The function of transporting the equipment to and from the parent ship and suspect vessels places constraints on the sensor equipment that can be used. These pieces of equipment need to be easily transportable (i.e. not too heavy, nor too bulky). Considerations should also be made on what to do should the equipment fall overboard during transportation. Lastly, the actual searching the ship function is conducted once all search equipment has been brought onboard the secured suspect vessel.

Functions 6.1, 6.2 and 6.3.2 are dependant on the intelligence provided before the search. Function 6.3.2 may even be modified as the search progresses on the suspect vessel. Function 6.3.1 is limited by the boarding team size, while function 6.4 is performed by the boarding team. This chapter focuses on the remainder – searching the suspect vessel.

F. IDENTIFYING THE TECHNOLOGIES AND EQUIPMENT

In order to recommend possible solutions to increase the search effectiveness over the current search method, a search for technologies that can be implemented to detect and identify the targeted cargos was conducted among existing industries. A list of technologies is identified. These technologies are studied more in depth to identify their 1) limitations, 2) feasibility to be used search a suspect vessel, and 3) whether equipment exists.

These technologies are then classified into 1) technologies that are implementable currently, and 2) technologies that are implementable in the not too distant future. Technologies that are implementable currently will have existing equipment that can be explored to improve the search effectiveness. These pieces of equipment were identified and their performances were modeled to measure the effectiveness they bring about as compared to current practices (baseline).

There are technologies that show great potential in improving the effectiveness of search, but due to various reasons, are foreseen not to produce any equipment by 2013-2014 that are suitable for MIO. That being said, it is still recommended that these technologies be monitored for future products that will become suitable for MIO. These technologies are classified and listed as "technologies that are implementable in the not too distant future".

1. Baseline Technology

a. Human Eye

(1) Technology: The human eye is the baseline sensor for this study. It is the oldest visual sensor a human being has. The human eye accommodates to changing lighting conditions and focuses light rays originating from various distances from the eye. When all of the components of the eye function properly, the eye takes in light reflected from the object that it is looking

at. This light is then converted to impulses and conveyed to the brain where an image is perceived. This is known as detecting the object. The image is then compared against either images in the brain's memory bank or information that the searcher is holding to identify and classify the object.

(2) Limitations: Remarkable the human eye may be, there are limitations that impact the search results. Most important of all is that the human eye is not able to see through walls. Containers will need to be selected and opened to see the contents within. This action usually requires a lot of time.

(3) Feasibility for Shipboard Use: Without doubts, human eyes are definitely feasible for shipboard use.

(4) Existing Products: The human eyes, brain and implementation through communications and motor functions as a system is the existing baseline. One of the biggest advantages of this baseline is that every ship crew has a pair of working eyes. This means that if need arises and when possible, more pairs of eyes can be recruited to form the sweep team so as to shorten the search duration.

2. Technology Implementable Currently

These are technologies that can be implemented currently and there are existing equipment that implement these technologies. These technologies will be discussed in detail, and existing products will be listed for consideration.

a. Ion Mobility Spectrometry

Ion Mobility Spectrometry (IMS) is a proven and currently used search technology that can handle the demands of the maritime environment as shown by its US Coast Guard use.[9] Current IMS systems are able to detect and

[9] Sul, Chih-Wu, Steve Rigdon, Tim Noble, Mike Donahue, Corey Ranslem, "Operational assessment of a handheld ion mobility spectrometry Instrument," http://ijims.ansci.de/pdf/4/1/Su_IJIMS_4_2001_1-11.pdf, 17 April 2008.

identify numerous explosives, narcotics, and chemicals. These qualities make it a good candidate for use in MIO operations.

(1) Technology: Ion Mobility Spectrometry detects and identifies trace amounts of substances down to the nanogram in size. The trace amounts are left behind when explosives or narcotics are packed into containers or handled by people. Swabs are used to collect trace particles from various surfaces such as walls, doors, handles, and people. The surface being inspected is swabbed once and the swab then carefully encapsulated in a plastic glove worn by the user until user is ready to analyze the swab.[10] The swab is then placed in the spectrometer for analysis. The traces are ionized using Ni63 or Am241.[11] The ions are then gated into a drift tube. An electric field in the drift tube causes the ions to drift towards a collector electrode, which emits an electric signal when struck by the ions.[12] An example of the drift tube can be seen in Figure 17.

10 Jeremiah W. Rekow, GM3 USCG, Ionscan Manager USCG PACTACLET, 17 April 2008.

11 Ibid.

12 Martinak, David, Andreas Rudolph, "Explosives Detection Using An Ion Mobility Spectrometer for Airport Security", http://ieeexplore.ieee.org/iel3/4941/13616/00626268.pdf?arnumber=626268, 17 April 2008.

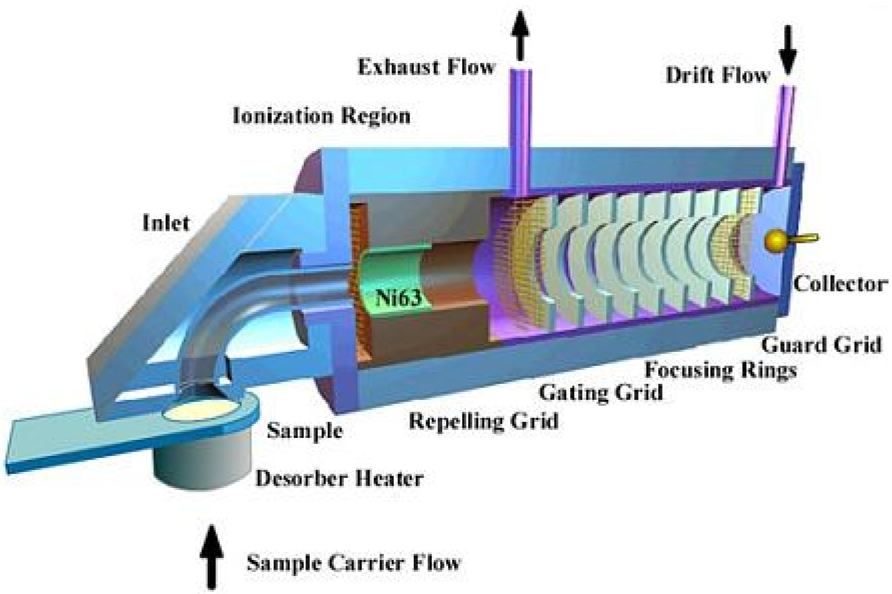

Figure 17: Ion Mobility Spectrometry Drift Tube[13]

Each ion generates a unique signal when making contact with the collector electrode at the end of the drift tube. The mobility (K) and the electric field (E) in the drift tube are related to the particle's drift velocity (vd) through the equation vd = K x E. The drift velocity calculated based on the measurements made at the collector is compared against known values of compounds to determine the species of the trace.[14]

(2) Limitations: The Operating limitations specified by manufacturers of different models that perform ion mobility spectrometry are an operating temperature of 32°F to 113°F or 104°F, depending on the model and, an operating humidity of 5% to 95% non-condensing.[15] Other limitations include the need for a clean swab for every sample. There is also the limitation of the battery life or electrical source depending on the model used.

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13 Smiths Detection, "Ion Mobility Spectrometry (IMS)," http://www.smithsdetection.com/eng/286.php, 17 April 2008.

14 Smiths Detection, "Ion Mobility Spectrometry (IMS)," http://www.smithsdetection.com/eng/286.php, 17 April 2008.

15 Thermo Electron Corporation, "EGIS Defender" http://www.envimet.com/pdfs/EGIS%20Defender%20Brochure.pdf, 17 April 2008.

(3) Feasibility for Shipboard Use: This technology is very feasible for shipboard use. It is currently used by the U.S. Coast Guard in the form of the IonScan 400 and the Sabre 4000.[16] The Coast Guard even has training centers in the U.S. that train search operators in the use of the technology.[17] No other limitations should limit this technology from being used aboard ship and being fully employed in MIOs.

The IonScan 400 weighs 47 lbs but is small (15.5 x 13.5 x 13") and comes in a carrying case that allows the boarding team to hoist the equipment onto the suspect vessel easily. The Sabre 4000 weighs 7 lbs and comes with a shoulder strap that allows the boarding team to bring equipment onboard the suspect vessel easily.

(4) Existing Products: There are several existing products that have been used since 1990, when the company Barringer, now Smiths Detection, introduced the IonScan.[18] The IonScan is a plugged in table top ion mobility spectrometer. It is also comparable to the competing EGIS Defender Explosives Trace Detection (ETD) system, which is manufactured by Thermo Electron Corporation. The IonScan is a staple at airport security checkpoints around the world, where it is used mainly for explosives detection.

The Sabre 4000 from Smiths Detection is, however, the best suited for shipboard use and can be seen in Figure 18. Its small portable size and weight at 14.5" long and 7lbs with 4 hour battery make the Sabre 4000 a truly mobile search device. This allows the search team to easily move about the ship while being able to analyze samples without leaving the area being searched. The Sabre 4000 can complete a full analysis of the sample in less than 20 seconds.[19]

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[16] Sul, Chih-Wu, Steve Rigdon, Tim Noble, Mike Donahue, Corey Ranslem, "Operational assessment of a handheld ion mobility spectrometry Instrument," http://ijims.ansci.de/pdf/4/1/Su_IJIMS_4_2001_1-11.pdf, 17 April 2008.

[17] Jeremiah W. Rekow, GM3 USCG, Ionscan Manager USCG PACTACLET, 17 April 2008.

[18] Jeremiah W. Rekow, GM3 USCG, Ionscan Manager USCG PACTACLET, 17 April 2008.

[19] Smiths Detection, "SABRE 4000," http://www.smithsdetection.com/eng/1523.php, 17 April 2008.

Figure 18: Sabre 4000[20]

The Sabre 4000 is capable of detecting numerous trace elements. It can detect the explosives RDX, PETN, TNT, Semtex, TATP, NG, Ammonium Nitrate and others. It can detect the narcotics Cocaine, Heroin, THC, Methamphetamine and others. It also can detect chemical warfare agents such as the nerve and blister agents Tabun, Sarin, Soman, Cyclosarin, Agent VX and VX, Nitrogen Mustard 3 and others. It even can detect the toxic industrial chemicals Hydrogen Cyanide (HCN), Phosgene, SO2, NH3 and others.[21]

Below are some examples of existing IMS Products in Table 8.

Manufacturer	Smiths Detection	Smiths Detection	Thermo Electron Corp
Product	IonScan 500	Sabre 4000	EGIS Defender
Easily Portable	No	Yes	No
Drug Detection	Yes	Yes	Yes
Explosive Detection	Yes	Yes	Yes
Power Source	115V Plug	Battery	115V Plug

Table 8: IMS Products

20 Smiths Detection, "SABRE 4000," http://www.smithsdetection.com/eng/1523.php, 17 April 2008.

21 Ibid.

(5) Logistics Requirements for IMS: The pieces of equipment listed above mostly require minimum maintenance. None of them require any scheduled maintenance. However, consumables such as swabs and gloves for the operators need to be procured in order to support the long duration of operations.

(6) Summary: Table 9 provides a summary of key characteristic of the IMS.

Sensing Technique	Ion Mobility Spectrometry
Max Effective Sensing Range	Limited by ions present in swab. Currently, the practice is to take sample swabs at 50 ft interval.
Max Search Lifespan	4 hours (dependant on battery life span).
Probability of Detection	95%
Existing Product	IonScan 400, Sabre 4000 and EGIS Defender

Table 9: Key Characteristics of the IMS

b. Dogs

(1) Technology: Dogs, in general, have a sense of smell about one hundred thousands times stronger than a human being's[22]. It has been estimated that a single search dog can achieve what twenty human searchers can do. Besides their strength in smell sensing for drugs, explosives and chemical agents, dogs' superior hearing (dogs can hear four times the distance humans can[23]) and night vision also enhanced their search capabilities for human and animals.

[22] Facts about Tracking, American Kennel Club, http://www.akc.org/press_center/facts_stats.cfm?page=12, 28 May 2008.

[23] 5 Ways Your Dog Senses The World Differently From You, http://www.theofficialanimalsite.com/5-ways-your-dog-senses-the-world-differently-from-you.php, 28 May 2008.

There are numerous ways to employ dogs for search operations. Knowing the search type will allow the best use of the type of search dogs. While most dogs are capable of all types of searches, they are usually trained to specialize in one area. The main types of work the dogs can do are generally categorized as airscent and trailing.

Airscent refers to search dogs that use airscenting techniques to search for the required items. Airscent dogs will ignore ground scent and will follow and locate people or items by catching the "hot" scent of people or items in the wind. This technique is highly effective for large area searches. The probability of detection depends greatly on the conditions of the air. The dogs can also pre-scent on the item that they should be searching before setting off for the search.

Another technique will be trailing or tracking search. This refers to the use of ground based scent in order to find the required item or human. This is usually utilized in human searches as scent is left behind by people walking. As the name suggests, the dogs will trail this scent until where the final spot of the search item is.

Dogs have been widely used for search operations for drugs, explosives and human or animals. The main advantage of using dogs for search operations is that it has been proven effective.

(2) Limitations: As in all kind of ‘sensors’, a ‘living sensor’ (dog) has its own limitations too. The following are some limitations and disadvantages of a search dog in such operations.

While mechanical and electrical related sensors will have power limitations, a dog’s stamina for a search is around thirty minutes before it reaches fatigue. As such, if a longer search is required, the canine has to be replaced by another dog.

Unlike test proven equipment, search dogs require a long period of training. It was estimated that it takes about six hundred hours of training for a dog to be field ready[24]. This presents a constant cost (both monetary and time) of training before they can be fielded.

As the search operations may last for ninety days, logistics requirements of dogs' food, waste disposal and a well-ventilated space for rest and sleep are of utmost importance.

It is important that the search dogs do not bring any form of diseases or contamination from suspect vessels to the mother ship. One way to prevent this is to have flea bath for the dogs after every search.

While it is not a well-documented fact that dogs get seasick on board a ship, many believe that search dogs can be trained to overcome them over time and training[25][26]. This will contribute to part of the training of a search dog for maritime operations especially for long-haul operations.

In general a search dog can search for almost anything, but they are usually trained in area of specialty (for instance, Heroin dog, Cannabis dog, Cocaine Dog Explosive A dog, Explosive B dog, etc). As such, this may require a large fleet of specialty dogs for different type of search.

Dogs cannot be used for stand-off search operation as the sensing distance of dogs are limited as well as dependant on the air conditions. (See Table 10 for the Probability of Detection).

Probability of Detection Based on Air Stability Class and Distance from the Source by the Dog Alone				
Air Stability Class	**100m**	**50m**	**25m**	**12.5m**
A (0.025)	5%	50%	75%	87%
B (0.050)	10%	55%	77%	89%
C (0.100)	35%	67%	86%	93%

24 SAR Dog Training, "http://people.howstuffworks.com/sar-dog4.htm", 28 May 2008.

25 Overcoming Motion Sickness in Dogs, "http://ezinearticles.com/?Overcoming-Motion-Sickness-in-Dogs&id=287359", 28 May 2008.

26 How to Travel Safely With Dogs, "http://www.thepetcenter.com/gen/travdog.html", 28 May 2008.

D (0.250)	80%	90%	95%	97%
E (0.400)	90%	95%	97%	99%
F (1.000)	95%	97%	99%	99%

Table 10: Probability of Detection by Dogs[27]

(3) Feasibility for Shipboard Use: Other than the issue of seasickness, dogs are definitely feasible for shipboard operations. Currently in some countries dogs have already been used by the coast guards for search operations[28]

Dogs can be heavy. For example, the average weight a Beagle is between 22 and 25 lbs[29] while a German Shepherd can weigh between 75 and 95 lbs[30]. This means that the dogs cannot be "piggy backed" onto the suspect vessel by the boarding team. However, the dogs can still be hoisted onto the vessel using harness attached to them. Figure 19 shows pictures of some of the harness currently used.

Figure 19: Available Harness to hoist Dogs[31].

27 Probability of Detection for Search Dogs or How Long is Your Shadow?, Hatch Graham, "http://www.sar-dog.org.nz/pdf/SAR-DOG_PoD.pdf", 28 May 2008.

28 Coast Guard Goes to Dogs for Bomb, Drug Searches, "http://goliath.ecnext.com/coms2/gi_0199-524129/Coast-Guard-goes-to-dogs.html", 28 May 2008.

29 Beagles, http://www.dogbreedinfo.com/beagle.htm, 18 May 2008.

30 German Shepherd Dogs, http://www.hoflin.com/BR/German%20Shepherd%20Dogs, 18 May 2008.

31 http://www.handicappedpets.com/acc/supsuit/index.html

(4) Existing Products: As mentioned earlier, coast guards have been utilizing dogs for searches and it has been a well-known fact that dogs are widely used in Search and Rescue (SAR) operations with impressive results. Different dogs possess different level of sensitivity. While some maybe better than the other, generally the following are popular choices for their size, intelligence, good listening skills, non-aggressive personality and a strong desire to retrieve something. German Shepherds, Labrador, Golden Retrievers, Bloodhounds, Beagles and Border Collies are generally common choice. Some smaller breeds have been successfully used by law enforcement and border security agents and these should be further investigated for possible use.

(5) Logistics Requirements for dogs: Having dogs onboard a naval ship will require special logistics to be catered for them. There is a need to either deploy a veterinarian onboard to provide medical care for dogs or train the onboard medical doctor basic animal medical care too. There is also a constant threat of dogs contracting virus or getting infested with fleas from suspect vessels that they searched. These virus or fleas may subsequently contaminate the mother ship. One way to reduce this threat is to shower the dogs after every operation.

(6) Summary: Table 11 provides a summary of key characteristic of the dogs.

Sensing Technique	Airscenting and trailing
Max Effective Sensing Range	12.5 - 100m
Max Search Lifespan	30 mins
Probability of Detection	5 - 99% depending on air conditions
Existing Product	German Shepherds, Labrador, Golden Retrievers, Bloodhounds, Beagles and Border Collies

Table 11: Key Characteristics of Dogs

3. Technology Implementable In Not Too Distant Future

These are technologies that show great potential in improving the effectiveness of search. However, existing equipment that uses these technologies are not suitable for MIO. These technologies, however, should be monitored for products that eventually will be suitable for MIO.

a. X-Ray

(1) Technology: Transmission X-rays penetrate the object under examination, revealing fine details, such as wires and other bomb components. Transmission X-ray images result when these X-rays pass through an object, and are absorbed rather than scattered. When viewed on a transmission monitor, these X-rays create a "shadowgram" image, similar to the result of a medical X-ray exam. "Shadowgram" images are generally high resolution, and result from the X-ray beam being absorbed by objects of varying densities. By comparison, a Z Backscatter image captures data from X-ray photons that are scattered from the object undergoing inspection. This primary scattering effect is known as "Compton Scattering". X-ray photons scatter differently when they encounter different types of materials. Compton scattering is material-dependent.

(2) Limitations: The main limitations of x-ray machines are the weight and bulkiness of the equipment. To allow the search team to carry out search onboard the target ship, portability is a key requirement. The weight and bulkiness of current available equipment in the market does not allow the equipment to be readily portable by the search team.

(3) Feasibility for Shipboard Use: For container and personnel searching, the existing equipments need to be carried onboard the target ship. The weight (~680kg for personnel x-ray machine and ~3000kg for container x-ray machine) of the equipment makes it infeasible to be brought

onboard the target ship. A more portable system with better penetrating capability is required.

(4) Existing Products: Existing equipment can be classified into (1) X-ray for personnel search, and (2) X-ray for cargo search.

Personnel search: AS&E's SmartCheck[32] system is an effective way to screen for contraband and threats hidden under a person's clothing. Its capability goes beyond that of metal detectors because it simultaneously detects both metallic and non-metallic objects, such as guns and knives, plastic and liquid explosives, composite weapons, drugs and other hidden threats and contraband. And its Z Backscatter image gives the operator a display of where the threat or contraband is hidden, thus eliminating the need for intrusive and time-consuming pat-down and strip searches. It is easy to use and depending on the operating mode, the system requires only one or two operators. The SmartCheck system is safe for all individuals and complies with all applicable U.S. personnel scanning regulations. An optional privacy filter protects the privacy of screened persons and still effectively displays threats.

Figure 20: AS&E's Smartcheck System

[32] AS&E's Smart Check, http://www.as-e.com/products_solutions/smart_check.asp

Cargo Search**:** AS&E's Cargo and Vehicle inspection systems[33] are engineered to provide security personnel with an effective means of detection without disrupting the flow of commerce.

AS&E's X-ray inspection systems that can detect a multitude of threats and contraband, including:

-Drugs

-Human Beings

-Plastic Weapons and Explosives, including car and truck bombs

-Radioactive Threats, including nuclear devices and dirty bombs

-Smuggled goods, such as alcohol, tobacco products, and other legal goods smuggled to evade duties (trade fraud)

-Weapons or other inorganic threats, including metal weapons and shielding to conceal radioactive materials

These systems can inspect cars, vans, and trucks, as well as palletized cargo, and air and sea cargo containers.

[33] AS&E's cargocheck, http://www.as-e.com/products_solutions/cargo_vehicle_inspection.asp, 17 April 2008.

Figure 21: AS&E's Cargocheck System

b. Millimeter Wave

(1) Technology: Millimeter-waves (MMW) are electromagnetic radiation that ranges with wavelengths from 10 millimeters to 1 millimeter in the electromagnetic spectrum, locating between the microwave and infrared. Their corresponding frequencies are from 30 GHz to 300 GHz. Due to this high frequency of MMW as well as their propagation characteristics, it is ideally suited for use in screening and imaging applications.

MMW works by radiating electromagnetic waves out to a target so as to generate an image based on the energy reflected from the target and the atmosphere. For example, MMW technologies are being used to detect guns concealed underneath clothing by the detection of the contrast between the warmer human body and the apparently cooler metal weapon.

The use of MMW technology is safe as it radiates out harmless waves to the environment therefore people are not exposed to any form of radiation.

(2) Limitations: There are two key limitations to the usage of MMW. The first limitation is the problem in detection from high stand off distance and the second limitation is that MMW is not able to penetrate through

metal materials. Not being able to penetrate through metal materials proved a big setback for this technology to be used onboard of a ship as most modern ship are made of metal thus limiting the search capabilities. By using metal material (e.g. aluminum foils) to wrap over drugs or explosives is another issue to the search capabilities of this technology.

(3) Feasibility for Shipboard Use: It is still possible to be used on ship but limiting the search capabilities to older ship (e.g. dhows) that are mostly constructed out of wooden materials.

(4) Existing Products : One of the possible products is the ST150 (Outdoor High Resolution Imaging) from Sago Systems.

Figure 22: ST150[34]

The ST150 passive millimeter-wave imager is a stand-off unit designed for outdoor perimeter and check-point security screening of suicide vests, bombs, guns, knives and other suspicious objects. The radiation-free system can be camouflaged to provide covert screening at a distance before entering a confined area or it can be located at a checkpoint. ST150 allows for remote security personnel to be situated at a safe distance immediately viewing the images from a command center over a standard wi-fi interface to a laptop computer. This allows authorities to isolate the threat from a distance and help prevent planned attacks. ST150 has been tested and evaluated by the U.S.

[34] Sago Systems, "ST150," http://www.sagosystems.com/Pages%20Folder/Products/products.html, 17 April 2008.

Government[35]. It is an excellent complementary security solution for courthouses, cruise ships, corporations, airports, visitor attractions, and many other locations.[36]

3. Summary of Technology

The technologies can be summarized as Table 12:

	Human Eyes	IMS	Dogs	X-ray	MMW
Human or Animals	x		x	x	x
Illicit narcotics	x	X	x		
Firearms	x			x	x
Explosives	x	X	x		
Advantage	• Proven • Widely available	• Portable	• Proven • Portable	• See thru' Metal	• No radiation. • Portable.
Limitations	• Cannot see thru' wall. – Need to open container to see what's hidden within.	• Need Traces	• Need Traces • Seasick • Need a large fleet • Additional Logistic required.	• Not easily portable • Human exposed to radiation	• Unable to see through metal.

Table 12: Summary of Technology

Both the Ion Mobility Spectrometry (IMS) and dogs are available now. Together these two technologies allow us to search for smuggled human or animals, illicit narcotics, and explosives. These technologies cover three of the four targeted cargos. As for firearms, because current x-ray and millimeter wave equipment do not offer feasible solution, human eyes are still needed for the search.

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[35] Sago Systems, "ST150," http://www.sagosystems.com/Pages%20Folder/Products/products.html, 17 April 2008.

[36] Sago Systems, "ST150," http://www.sagosystems.com/Pages%20Folder/Products/products.html, 17 April 2008.

4. Technology Implementable But Not Studied

There are technologies or existing equipment that are being used but not studied due to resource constraints and also limited potential of the equipment. These are presented here for further discussion outside this study.

a. Borescope / Fibrescope / Videoscope

A Borescope is an optical device consisting of a rigid or flexible tube with an eyepiece on one end, an objective lens on the other linked together by a relay optical system in between. The optical system is usually surrounded by optical fibers used for illumination of the remote object and a rigid or flexible protective outer sheath. The remote object is illuminated and an internal image formed by the objective lens is relayed to the eyepiece which magnifies the internal image and presents it to the viewer's eye.

Variations to the Borescope are Fibrescope and Videoscope. Fiberscopes use coherent image fiberoptics to relay the image to one's eye through an eyepiece while a Videoscope is an advanced type of Borescope that houses a very small Charge Coupled Device (CCD) chip embedded into the tip of the scope. The video image is relayed from the distal tip and focusable lens assembly back to the display via internal wiring. The image quality of a videoscope is superior to a fiberscope and could be compared to that of a high-end Video Camcorder.

Being narrow (a Videoscopes are normally 10 mm or less in diameter), compact and highly portable, the scopes are used for inspection work where the area to be inspected is inaccessible by other means. However in order to see what is hidden inside a container, openings are needed to put the scopes in. The scopes will be useless if there is no opening. If there is a need to "see" what is hidden inside a container, it may be faster to use a Borescope than to physically open a container and search within, but it is believed that this improvement over the baseline technology is limited and is much lesser than if either IMS or dogs are used. Therefore, Boresecope and similar kinds were not explored further.

b. Infrared Sensors

Infrared sensors, such as Forward Looking InfraRed (FLIR), or an infrared camera, are devices that form images using infrared radiation, similar to common cameras that form images using visible light. Instead of the 450 – 750 nm range of the visible light camera, infrared cameras operate in wavelengths as long as 14,000 nm (14 µm). All objects emit a certain amount of black body radiation as a function of their temperatures. An infrared sensor can detect this radiation in a way similar to how an ordinary camera does with visible light.

This technology looks attractive initially as the operator may be able to detect a warm body hidden inside a container when he senses that a container is hotter than other nearby container. However, this technology has its limitation. In the hot day, say in the Straits of Hormuz, where temperature in the day can be as high as 111 ^{o}F, a container will be emitting more radiation than the body it contained, the container with the hidden warm body will therefore be seen to be as hot as the surrounding containers. In summary, Infrared sensor will work only if there is thermal difference between the container and its surrounding containers. Due to this limitation, the focus of the study was placed elsewhere.

G. MODEL

Both the Ion Mobility Spectrometry and dogs are recommended as possible solutions to improving search. In order to measure how effective these solutions are, the equipment was modeled so as to measure the effectiveness of sensors used for searching a suspect vessel with an area to be searched of approximately 250 m^2. Both an exhaustive and a random search model were used to bound the results. The exhaustive model would identify the upper bound of performance based upon an ideal search situation while the random search would model near worst case search situation and performance and performance. The MOEs are 1) Time to search the entire suspect vessel, 2) the Probability of Detection (Pd) achieved in a given search time of two hours, and 3) the time taken to search the vessel in order to achieve a required Pd. The results were compared with the effectiveness of searching using the unaided human eyes (baseline case).

1. Model Description

A benchmark was given based on past real operations experiences estimated two hours for an approximately 1,000 GT cargo ship and four hours for large super container ships. Estimates of the performance of various sensors were estimated based upon real data from various sources that was used to fit the simplified model. Most sensors provide probabilities of detection or at least very good estimates of them. However, false alarm rates (FAR) were not available with only one sensor's FAR being found. Because of the lack of data of FAR, they were not taken into consideration in the models. It is realized that false alarms would degrade search time in the real world by requiring time to verify that each false alarm was indeed a false alarm and not a true positive.

Two spreadsheet models were created. The first was an exhaustive search model and the other a random search model. The exhaustive search model is based upon equation (9.1) [37] while the random search model is based upon equation (9.2)[38]. These models assume that the lateral range curve is general and that the sensor has a probability of detection of 1. The models were run for each sensor until the cumulative detection probability (CDP) reached 1. A CDP of 1 means that the entire area to be searched has been completely searched in these models. The true probability of detecting any targeted cargo is then the sensor's probability of detection once an exhaustive search has been completed. If the search were to be stopped before CDP were to reach one in

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[37] Pilnick Steven. "OA 3602 Search & Detection: Area Search and Patrol," Slide 6.

[38] Wagner, Daniel H., Charles Mylander, Thomas Sanders. "Random Search" *Naval Operations Analysis, 3rd ed.*, 174.

the model (i.e. not the entire area has been searched), then the probability of detection would be the current CDP multiplied by the probability of detection of the sensor as shown in equation.

$$CDP = F_T(t) = \begin{cases} 0 & t < 0 \\ \dfrac{vW}{A}t & 0 \le t \le A / vW \\ 1 & t > A / vW \end{cases} \tag{9.1}$$

$$CDP = F_T(t) = 1 - e^{-\lambda t} \tag{9.2}$$

$$\text{Probability of Detection} = \text{CDP} \times \text{Sensor's Probability of Detection} \tag{9.3}$$

For the models, the sweep width and speed of advance of each sensor were needed. Sweep width was based upon the estimated range of the sensors after significant research. The speed of advance was then estimated based upon the time it would take to search a circle with a diameter of the sweep width.

2. Time to Search Entire Suspect Vessel

The time taken to search was then calculated for a 1,000 GT vessel, which would have an approximated deck area of 250 m^2 to search. The results can be seen in Table 13.

Equipment	Pd	Sweep Width (m)	Speed of Movement (m/s)	Area Searched (m^2)	Exhaustive Search Time (min)	Random Search Time (min)
Human Eyes	0.6	2	0.033	250	63	330
IMS	0.95	6	0.042	250	17	88
Dogs	0.95	2	0.1	250	21	110

Table 13: Search Model Results

As can be seen in Table 13 it takes shorter to search the entire vessel when using search equipment as compared to using just human eyes. It is important to note that the probability of detection for each sensor has yet to be considered. As can be seen later, when the probability of each sensor is considered, the differences will be even more drastic.

3. Probability of Detection Achieved for a Given Time to Search

The sensors can also be compared in their capability to maximize probability of detection within a given time. The time given for search of a 1,000 GT vessel with an approximate deck area 250 m^2 is stated to be approximately two hours according to the project's operations management plan. In this two hour time period, certain probabilities of detection are possible with the given sensors and can be seen in Table 14. The results demonstrate the advantage of sensors over simply using human eyes.

Equipment	Sensor Pd	Sweep Width (m)	Speed of Movement (m/s)	Area Searched (m^2)	Max. Pd Achieved in 2 hours	
					Exhaustive Search	Random Search
Human Eyes	0.6	2	0.033	250	0.82	0.41
IMS	0.95	6	0.042	250	1	0.95
Dogs	0.95	2	0.1	250	1	0.95

Table 14: Achievable Pd in Given Time

The results show that both IMS and dogs can achieve a probability of detection between 0.95 to 1 when searching a 250 m^2 vessel for 2 hours. The results also show that for a given time, the search equipment can achieve higher probability of detection than using human eyes only.

4. Time Needed to Search Suspect Vessel to Achieve a Given Probability of Detection

High rates of success demand come at a higher cost. To achieve a probability of detection that would satisfy a commander's reasonable desire to ensure a ship is clean, the time taken to search must be increased for some sensors. The times necessary to achieve 0.95 probability detection for a 1,000 GT vessel with an approximate deck area 250 m^2 can bee seen in Table 15. These results again reaffirm the improvement of using sensors over only the human eye especially seeing as it is impossible to truly achieve a probability of detection of 0.95 using the human eye.

Equipment	Sensor Pd	Sweep Width (m)	Speed of Movement (m/s)	Area Searched (m^2)	Time (min) to Achieve Pd of 0.95	
					Exhaustive Search	Random Search
Human Eyes	0.6	2	0.033	250	204	N/A
IMS	0.95	6	0.042	250	17	91
Dogs	0.95	2	0.1	250	21	115

Table 15: Time to Achieve Pd of 0.95

The results show that IMS can achieve the required probability of detection the quickest. When searching a 250 m^2 vessel, there is little difference in the time taken for both IMS and dogs, however, there is a marked improvement when using the search equipment instead of purely human eyes.

5. New Sensor Recommendations

Based upon the results of the models for the various sensors, recommendations were made for the new sensors that will hopefully be developed for MIOs soon in the future. These sensors are the millimeter wave and x-ray sensors. Equipment using these technologies currently exists but none are really suitable for MIO. The desire is for these sensors to ultimately improve upon the performance of the human eye being used as an instrument for search. The recommendations can be seen in Table 16.

X-Ray Sensor	
Sensor Sweep Width	2 m
Speed of Movement	0.067 m/s
Recommended Sensor Pd	>0.8

Table 16: New Sensor Recommendations

The parameters were chosen for various reasons. In order to see across the width of a container and to match eye performance, 2 m were selected as sweep width. The speed of movement was estimated to be 0.0667 m/s with the hope that it would improve upon the speed of a sight search that would require moving objects or containers to search. The sensor probability of detection was also chosen to be an improvement over the human eye and to ensure that the improvement given would be worth the technology investment.

H. CONCLUSION

The Ion Mobility Spectrometry (IMS) and dogs are recommended as solutions in the study. As can be seen from the results of this model, both IMS and dogs improve the search efficiencies.

Costs to operate and support using these pieces of equipment are discussed in Chapter X.

VII. INFORMATION SUPERIORITY

A. INTRODUCTION

1. Purpose

During Maritime Interdiction Operations, it is vital to obtain and maintain information superiority. Reliable systems must be in place to collect intelligence both on the macroscopic and microscopic levels. That information is of no use unless it can be analyzed and then used. Thus, a need exists to have reliable communication systems throughout the operation. Effective communications must exist between crew members on the suspect vessel, between the suspect vessel and the mother ship, and between the mother ship and shore installations around the globe.

2. Approach

In keeping with the timeframe of 2013-2014, surveys were taken of the current technological landscape to find systems that would be suitable for MIO operations. The team studied a number of systems, conducting analytical trade studies, to best weigh them against identified requirements. The team then proposed recommendations for utilization in each area.

3. Current Practice

The current practice of intelligence collection has just started to take advantage of available technology. On a macroscopic level, intelligence is being collected using traditional ISR (Intelligence, Surveillance, and Reconnaissance) means. On the microscopic level, technology can be much better used. It was just in November of 2006 that the Coast Guard began using biometric technology in immigration operations. The team believes that technology could be leveraged and used in Maritime Interdiction operations. In the area of communications, current practice is to use hand-held radios to communicate between the boarding team and the mother ship. These radios have range limitations and do not have the ability to simultaneously transmit and receive voice and data. As biometric data is collected, reliable communications are needed to transmit the data and perform near-real-time analysis of that data. Additionally, the current tactical radios being used have shortcomings when attempting communications in the interior of a metal-hulled ship. The channel environment introduces significant Rayleigh fading, making these internal communications difficult and unreliable.

4. Problem Definition

The problem is to research and recommend reliable systems for collection of intelligence on the macroscopic and microscopic levels. Additionally, current technology was researched in order to recommend systems to use in transmitting communications internally on and within the suspect vessel and externally, both between ships and globally.

5. Functional Decomposition

7.1 To Collect Information

7.1.1 To Collect Microscopic Intelligence

7.1.1.1 To Perform Biometric Collection

7.1.1.2 To Conduct Non-networked Computer Exploitation

7.1.2 To Collect Macroscopic Intelligence

7.2 To Transmit Information

7.2.1 To Transmit Communications Externally

7.2.2 To Transmit Communications Internally

B. COMMUNICATIONS

1.→ External Communications

a. Background

During MIO operations when a ship is identified as a suspicious target based on intelligence sources, there is a need for the boarding team to board the target ship and conduct the interdiction operations. The means of communications for the boarding team to send voice or data back to the mother ship is critical for the success of the operation. Communication links enable the whole team to achieve common situational awareness throughout the interdiction.

The mother ship also requires communications with other military or non-military MIO stakeholders or partners to access or retrieve relevant intelligence information during the execution of the MIO operation. This requirement includes transmitting scanned "biometric" data to relevant authorities for verification and validation or accessing data via corporate secure intranets to exchange important files or information.

b. Requirements

1. Develop ship-to-ship communication links for MIO boarding teams to communicate back to mother ship.

2. Develop ship-to-global communication links for the mother ship to communicate with global MIO partners or stakeholders.

c. System Proposals

1. Ship to Ship: The two options for ship to ship communications are as follows:

- Setting up point-to-point data link communications between the mother ship and the interdicted target ship.

- Setting up data link communications between the mother ship and the interdicted target ship via a relay. The relay can be implemented using a UAV or satellites. However, due to the higher operating costs of satellite communications, the use of UAV relay is recommended since the UAV is also employed for other MIO functions as explained in Chapter 8.

The first option (point-to-point data link communications) is preferred, as it does not introduce another point of failure (i.e., UAV and satellite) as in the second option. Moreover, in the majority of MIO operations, the target ship is within visual range (~8 nm) of the mother ship. Hence, the use of a relay is unnecessary.

(2) Ship to Global: Due to the long distance required by the ship-to-global communications, satellite communication is suitable.

Figure 23 illustrates the external communication architecture described in this section.

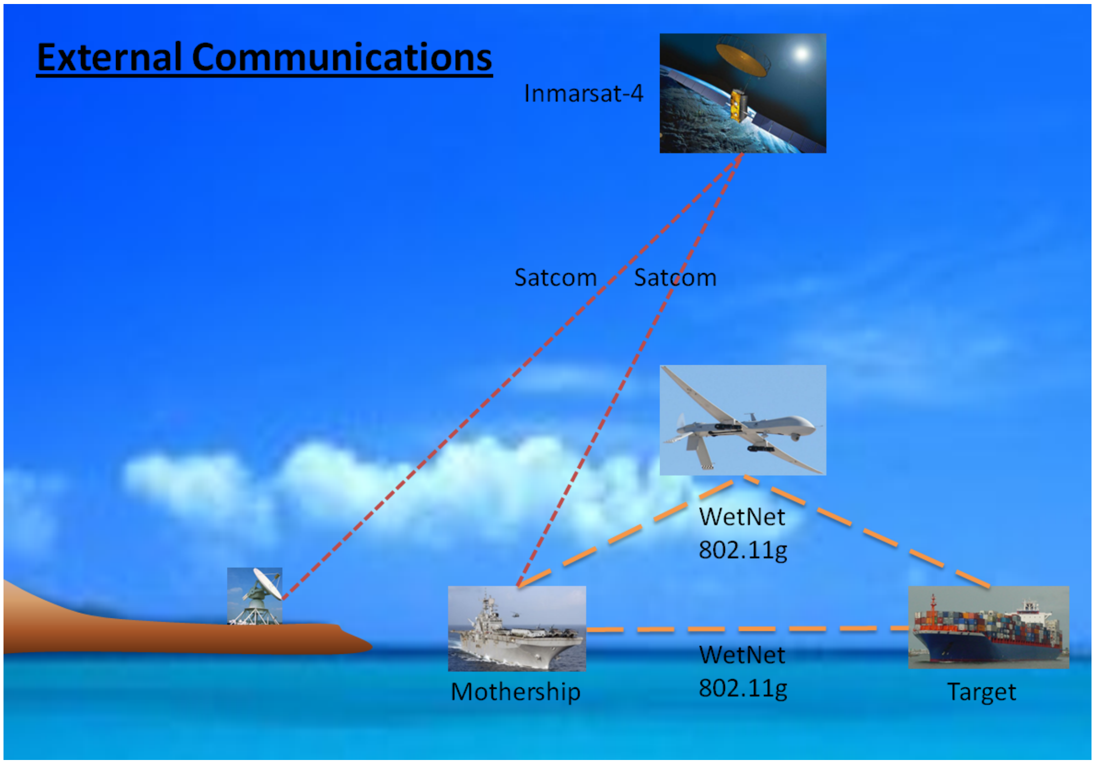

Figure 23: Conceptual Design of MIO External Communications

d. Ship-to-Ship Communications.

Ship to ship communication requires the bi-directional transfer of voice and data between two nodes. For MIO operations, the key system design issues include environmental conditions, effective data throughput, need for encryption, link performance, and inter-operability. The WetNet system by Harris Corporation has factored all of these issues into its design and hence, it is recommended for use here.

(1) Description: The WetNet system by Harris Corporation[39] is an IP-based network radio system based on the IEEE 802.11g protocol[40] with a maximum data rate of 54 Mbps. The system consists of a high-data rate network centric protocol with extended range capability and it can operate at

[39] Christopher D. Moffatt, "High Data Rate, Line of Sight Network Radio for Mobile Maritime Communications (Using Harris WetNet Technology)", Harris Corporation

[40] IEEE 802.11 Standard. http://standards.ieee.org/getieee802/802.11.html

various military and commercial frequency bands. The WetNet system has the following benefits:

- It is compatible with standard IP addressing and network topologies, including ad-hoc mode or infrastructure mode.
- It uses standard Ethernet-based physical device interfaces. This allows for convenient connection of external devices to facilitate voice and data transmission.
- It has multiple levels of cyclic redundancy checks (CRC) and integrated data encryption ensuring data integrity and security.
- It has a data packet structure with guaranteed delivery. This ensures that 100% of all data is delivered to the destination node.[41]
- It uses advanced OFDM waveforms with convolutional coding and scrambling.

This system leverages on the benefits of the 802.11 standards[42] as follows. Data is transmitted in 'bursts' of very short duration (microseconds) compared to the coherence time communications channel, $T_s << T_c$, resulting in slow fading. Slow fading is desirable as it reduces the effect of phase shifts due to Doppler spreading. OFDM modulation is inherently robust to multipath effects. This is because $Ts >> \sigma T$, which results in flat fading. Flat fading is desirable as it reduces ISI due to multipath effects. The 802.11 ARQ protocol ensures that all data packets are delivered by issuing an acknowledgment for each packet transmitted. Hence, packets missed because of LOS blockages are re-transmitted.[43]

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41 Christopher D. Moffatt, "High Data Rate, Line of Sight Network Radio for Mobile Maritime Communications (Using Harris WetNet Technology)", Harris Corporation

42 IEEE 802.11 Standard. http://standards.ieee.org/getieee802/802.11.html

43 Ibid.

(2) Key Design Considerations: The system is designed around low cost commercial 802.11(x) chipsets.[44] The waveforms are translated to frequencies as desired by the users for their unique requirements. High gain antennas, power amplifiers and LNA are added to overcome path loss at long ranges. Software modifications ensure 802.11 COTS products can function properly at long ranges. In addition, peaks of communication waveforms are reduced to reduce DC power consumption by the system. Additionally, data encryption for secured communications is layered into the protocol.

(3) System components: At each node, there is an 802.11 transceiver. At the transmit node, there is a power amplifier. At the receive node, there is a Low Noise Amplifier. At each node, omni or directional antennas can be used depending on the range required.

(4) Link analysis: The purpose of link analysis is to obtain the system signal to noise ratio (SNR) for performance assessment. This is because SNR determines the bit error rate that in turn determines the quality of service or accuracy of the data. A sample calculation of the SNR using representative figures (exact figures of the WetNet system are unavailable) is shown below.

$$SNR = \frac{P_T G_T G_R}{L_c k B T_s} \tag{9.4}$$

Using T_s=500K, L_c=150dB, $P_T G_T$=30 dBW, B=10 MHz and G_R=20dB, yields

$$SNR = \frac{1000 \times 100}{1 \times 10^{15} \times 1.38 \times 10^{-23} \times 10 \times 10^{6} \times 500} = 32\, dB \tag{9.5}$$

A SNR of 32 dB indicates excellent performance given added noise.

(5) Performance and Test results: Field tests were conducted by Harris Corporation over the ocean to validate the WetNet system's

44 Christopher D. Moffatt, "High Data Rate, Line of Sight Network Radio for Mobile Maritime Communications (Using Harris WetNet Technology)", Harris Corporation

performance in a representative maritime environment. Of particular interest to MIO was the boat to air field test. A Cessna 172 was flown at 3500 ft above MSL fitted with a small omni antenna mounted to the bottom of the fuselage. The boat was fitted with both omni and directional antenna at 15 ft above MSL. The data throughput was then measured at various distances and are tabulated in Table 17. Longer distances can be achieved by additional link gains.[45] Table 17 shows that WetNet's performance is suited for Maritime Interdiction Operations, as it achieves high throughput even at a distance significantly greater than that of a standard MIO.

Table 17: WetNet Performance

Airplane Antenna (3500 ft above MSL)	Boat Antenna (15 ft above MSL)	Distance (miles)	Throughput (Mbps)
Omni	Directional	90	5.4
Omni	Directional	88	10.3
Omni	Directional	86	12.4
Omni	Omni	40	9.15

(6) Ship-to-global Communications: Fleet Broadband is the first maritime communications service to provide broadband data and voice, simultaneously, through a compact antenna on a global basis. The services are supported by two of Inmarsat's heavyweight I-4 satellites that were operational in early 2007.[46]

45 Christopher D. Moffatt, "High Data Rate, Line of Sight Network Radio for Mobile Maritime Communications (Using Harris WetNet Technology)", Harris Corporation

46 Jane's Space Systems And Industry. Inmarsat 4. [Online] July 12, 2007. http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jsd/jsd_a082.htm@current&pageSelected=allJanes&keyword=inmarsat.

(7) Specifications: The specifications of the types of antennas and

Inmarsat 4 are indicated in the Tables 2 and 3. Both antennas shown in Table 18 are capable of being utilized for Fleet Broadband operation. Table 19 gives the specifications of the two current Inmarsat satellites currently in operation.

Table 18: Specifications of Fleet Broadband Antennas

	FB250	FB500
Data		
Standard IP	Up to 284 kbps	Up to 432 kbps
Streaming IP	32, 64, 128 kbps	32, 64, 128, 256 kbps
ISDN	-	64 kbps
Voice	4kbps digital 3.1 kHz audio	
Fax	Group 3 fax via 3.1 kHz audio	
SMS	Standard 3G (up to 160 characters)	
Antenna (Diameter/ Height/ Weight)	25 cm/ 28 cm/ 2.5 kg	57 cm/ 68 cm/ 18 kg
Frequency Band	Rx: 1525.0 – 1559.0 MHz Tx: 1625.0 – 1660.5 MHz Ch. Spacing: 1.25 kHz – Rx.	

Table 19: Specifications of Inmarsat 4 F1 and F2

Inmarsat 4 F1	
Launched:	11 March 2005 by Atlas V-431 from Cape Canaveral LC-41

Location:	64°E
Design life:	18 years
Contractors:	EADS Astrium: integrator, bus and payload; Northrop Grumman: reflector; EMS Technologies: antenna system
Transponders:	228 narrow-spot (1.1°) beams; 19 wide-spot beams; single global beam. Up to 630 200 kHz channels, dynamically allocated to beams.
Principal applications:	Mobile communications
Configuration:	Eurostar E3000 bus with 9 m deployable reflector. Body dimensions 7 m x 2.9 m x 2.3 m
Mass:	5,950 kg launch, 3,340 kg dry
Power system:	45 m-span hybrid (GaAs and Si) ten-panel solar array, delivering 13 kW
Inmarsat 4 F2	
Launched:	8 November 2005 by Zenit 3SL from Sea Launch platform Odyssey from Cape Canaveral LC-41
Location:	53°W
	Rest of the specifications are similar to Inmarsat 4 F1

(8) MOE: The measure of effectiveness of communications was based the amount of downtime of communication links during actual operations. This MOE was applicable, because if communication links were unusable, the communication system was deemed to have failed.

(9) MOP: There were 2 measures of performance proposed for the external communications. Namely, the time required to transmit different sizes of the data (~4 Mb for the thumb and iris biometric data of 10 people)

across the communication links, and in addition, the error rates of the data transmitted.

(10) Recommendations: The recommendations for external communications were to set-up the ship to ship communications using WetNet technology and engage the Fleet broadband services provided by Inmarsat for the ship-to-global communications. This recommendation provides seamless communications for all parties involved during MIO operations.

2. Internal Communications

a. Background

The inherent dangerous nature of MIO operations necessitates reliable and robust communications between boarding team members as well as the parent ship. No matter where a team member is onboard the suspect vessel, he or she must be able to use his tactical radio to communicate with other members of the team to safely execute these complex operations. The inherent nature of a target ship's hull introduces significant complexity to the channel environment in which signals are transmitted and received.

b. Requirements

- Must operate in an intensely Rayleigh faded environment with disproportionally greater attenuation (due to the metal super-structure) in any direction than free space path loss.
- Support voice and data simultaneously.

c. Findings

Four radio systems (802.16d, ITT Mesh, Trellisware and 802.11b) were compared in an NPS thesis. Trellisware was shown to be vastly superior to the other four radio systems.[47]

d. 802.11b Conclusions

- Performance was highly reliant on power supplied. As power was decreased to the system, latency increased substantially. The amount of available power is always limited by the weight of the transmitter and available battery power. Therefore
- As the apparent speed of a radio's movement increased, both latency and packet loss increase. "Speed" in this sense refers to the rate at which a radio moves from a fading zone to a constructive interference zone. This movement effectively modulates the received waveform. As the rate of modulation increases, the performance of an 802.11b system decreases.
- Increasing values of inter-reflection spacing causes greater amounts of inter-symbol interference (ISI). This phenomenon causes the radio to react in order to guarantee that the packet was received intact. The reaction in this case is to simply retransmit portions of the original message. This retransmission takes more time, which can be measured in the overall average latency. The effect of

[47] Fuller, Randal. "Performance Measurements of Network Radios in Harsh Multi-path Environments". NPS Thesis, September 2008

increasing inter-reflection spacing is not as pronounced as the Doppler shift effects; however it is still visible.

e. *Trellisware Conclusions*

- Average latency remained constant for all permutations of channel parameters.
- As power decreased, degree of packet loss increased.
- Degradation also occurred with increasing inter-reflection spacing. The degradation was negligible compared to 802.11b tests.
- Trellisware did prove to be immune to Doppler shift.
- Trellisware also has the ability to transmit at ranges of 100 nm when unobstructed, allowing voice communications to reach back to the parent ship.
- Trellisware has an automatic relay capability built into the radio. The algorithm for that relay functionality does not utilize routing like an IP network, but utilizes a flooding approach, whereby all information is relayed using only a minimum of computation. This allows more opportunities for forward error correction strategies to overcome channel fading conditions while also serving to effectively amplify a given signal. This relay capability allows the Trellisware radios to communicate ‘around’ the walls of a ship vice having to go through them.
- Trellisware, at the time of the writing of this report, had an insufficient amount of available throughput in order to support the biometrics. However, if the radio were able to

surpass WetNet's performance (without trading performance in any other areas), then Trellisware may be ideal for both internal and external communications.

f. Recommendations

In the current format, tactical radios based on the Trellisware technology would be ideal for the MIO environment. Trellisware radios cost approximately about $6,000 each and are approximately technology readiness level seven. When confined within a possibly large, steel-hulled suspect vessel the radio must be immune from the numerous Doppler shifts introduced by the frequent reflections within the vessel. While this does not meet all the requirements introduced above, it is the best option at the current time.

C. INTELLIGENCE

1. Microscopic Intelligence Collection

a. Biometric Collection

(1) Introduction to Biometrics: Biometrics is defined as:

> "The development of statistical and mathematical methods applicable to data analysis problems in the biological sciences. The term 'biometrics' is derived from the Greek words bio (life) and metric (to measure). For our use, biometrics refers to technologies for measuring and analyzing a person's physiological or behavioral characteristics, such as fingerprints, irises, voice patterns, facial patterns, and hand measurements, for identification and verification purposes."[48]

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48 "Biometrics Comparison Chart", National Center for State Courts, http://ctl.ncsc.dni.us/biomet%20web/BMCompare.html#aspects

As technology advances and improves, the use of biometrics for identification and verification has become increasingly affordable and accurate. Biometrics can help to speed up the process of identification and verification significantly.

(2) Types of Biometrics: There are many types of biometrics, and

each type has its advantages and disadvantages. Below is a chart from Court Technology Laboratory of the National Center for State Courts comparing different types of biometric measurements.

BIOMETRICS COMPARISON CHART

Biometric	Verify	ID	Accuracy	Reliability	Error Rate	Errors	False Pos.	False Neg.
Fingerprint	✔	✔	◎◎◎◎	►►►	1 in 500+	dryness, dirt, age	Ext. Diff.	Ext. Diff.
Facial Recognition	✔	✘	◎◎◎	►►	no data	lighting, age, glasses, hair	Difficult	Easy
Hand Geometry	✔	✘	◎◎◎	►►	1 in 500	hand injury, age	Very Diff.	Medium
Speaker Recognition	✔	✘	◎◎	►	1 in 50	noise, weather, colds	Medium	Easy
Iris Scan	✔	✔	◎◎◎◎	►►►	1 in 131,000	poor lighting	Very Diff.	Very Diff.
Retinal Scan	✔	✔	◎◎◎◎	►►►	1 in 10,000,000	glasses	Ext. Diff.	Ext. Diff.
Signature Recognition	✔	✘	◎◎	►	1 in 50	changing signatures	Medium	Easy
Keystroke Recognition	✔	✘	◎	►	no data	hand injury, tiredness	Difficult	Easy
DNA	✔	✔	◎◎◎◎	►►►	no data	none	Ext. Diff.	Ext. Diff.

Biometric	Security Level	Long-term Stability	User Acceptance	Intrusive	Ease of Use	Low Cost	Hardware	Standards
Fingerprint	►►►	►►►	►►	Somewhat	►►►	✔	Special, cheap	Yes
Facial Recognition	►►	►►	►►	Non	►►	✔	Common, cheap	?
Hand Geometry	►►	►►	►►	Non	►►►	✘	Special, mid-price	?
Speaker Recognition	►►	►►	►►►	Non	►►►	✔	Common, cheap	?
Iris Scan	►►►	►►►	►►	Non	►►	✘	Special, expensive	?
Retinal Scan	►►►	►►►	►►	Very	►	✘	Special, expensive	?
Signature Recognition	►►	►►	►►	Non	►►►	✔	Special, mid-price	?
Keystroke Recognition	►►	►	►►►	Non	►►►	✔	Common, cheap	?
DNA	►►►	►►►	►	Extremely	►	✘	Special, expensive	Yes

Figure 24: Biometric Comparison Chart

The symbols in Figure 3 are based on expert opinion for each Biometric. A check mark means a particular biometric satisfies the requirement. For accuracy, a greater number of circles indicates greater accuracy. In the other columns, green indicates better performance in that requirement than yellow, which is better than red. The terms Ext Diff (Extremely Difficult), Very Diff (Very Difficult), Difficult, Medium and Easy used in Figure 24 are used to define the level of difficulty for a False Positive or False Negative identification. Based on Figure 24, the required inputs were narrowed down to Fingerprint, Iris Scan and Retinal Scan as they can be used for verification and identification. DNA is not shortlisted due to user acceptability and possible legal issues. The retinal biometric is less error prone and very difficult to fake, but "during a retinal scan, the user must remove glasses, stare at a specific point, and hold their head still for 10-15 seconds" "to complete the scan."[49] This could prove difficult during a boarding situation for an uncooperative crew member. However, by the time the scan would be conducted, the situation would be stable onboard the suspect vessel with the crew already subdued, lessening the probability of difficult interactions with the crew. If the crew refuses to hold still for the retinal scan and there has been no provocation, the boarding team will have to use the fingerprint and iris data.

(3) Background work on Biometrics Used for Verification and Identification: Many countries have implemented a biometric passport and these passports are mainly used due to International Civil Aviation Organization's (ICAO) requirements. The information in the following paragraphs is extracted from an ICAO working paper on machine readable travel documents (MRTD).[50] The International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) standards incorporated into the e-passport specification are: Facial Image Format for Interoperable Data Interchange (ISO/IEC 19794-5); Iris Image Format for Interoperable Data Interchange (ISO/IEC 19794-6); Fingerprint Image Format for Interoperable Data Interchange (ISO/IEC 19794-4); Fingerprint Minutiae Format For Interoperable Data Interchange (ISO/IEC 19794); Fingerprint Pattern Format for Interoperable Data Interchange (ISO/IEC 19794-3)

49 "How does a Retinal Scan Work?", wisegeek, http://www.wisegeek.com/how-does-a-retinal-scan-work.htm

50 "Technical Advisory Group on Machine Readable Travel Documents" page 25 to 31, *ICAO TAG-MRTD/17-WP/16*, 1 June 07

The face record format (facial image) requires that the header and the entire data structure be CBEFF compatible and the image data be encoded using JPEG to JPEG2000. Compression of the facial image to 15 Kb to 20 Kb is recommended in the ICAO paper.[51] The term CBEFF stands for Common Biometric Exchange Formats Framework, which is a biometric standard. The term JPEG stands for Joint Photographic Experts Group, which is a type of data compression standard for images. JPEG2000 is a more recent data compression standard by Joint Photographic Experts Group.

Based on the ICAO paper, fingerprint scanners should capture fingerprints at a minimum resolution of 500 pixels per inch (ppi) in both the detector row and detector column directions. Both the white signal-to-noise ratio and black signal-to-noise ratio of the scanner should be greater than or equal to 125. At least 80 percent of the fingerprint images taken with a given scanner must have a gray-scale dynamic range of at least 200 gray levels and at least 99 percent shall have a dynamic range of at least 128 gray levels within the scanner hardware. Gray-scale linearity and uniformity within the scanner must be verified with test patterns (ISO/IEC JTC 1/SC 37 N 466).[52] Gray-scale finger image data may be stored, recorded, and transmitted in either compressed or uncompressed form. Compressed data is highly preferred for purposes of transmitting large quantities of data from multiple people. Images with a resolution of 500 ppi can be compressed using Wavelet Scalar Quantization (WSQ) with a 15:1 compression ratio or with JPEG at a 5:1 compression ratio. The optimal compressed size for a fingerprint image was estimated by ICAO to be approximately 10 Kb per finger.[53]

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51 "Technical Advisory Group on Machine Readable Travel Documents," 27 -28, *ICAO TAG-MRTD/17-WP/16*, 1 June 07

52 Ibid., 29.

53 "Ibid., 30.

According to the ICAO paper, the optimal compression size for an iris image is 30 Kb per eye. If JPEG or JPEG2000 compression is used, a compression factor of 6:1 or less is recommended. The image should have a dynamic range spanning at least 256 gray levels. The iris image within the scanner should have a minimum of 90 gray levels between the iris and sclera and a minimum of 50 gray levels separation between iris and pupil for all eye colors. Within the scanner, at least 70 percent of the iris should be visible. The minimum digital iris diameter should be comprised of at least 100 pixels, with 70 pixels between the left or right edge of the iris and the closest edge of the image, and at least 70 pixels between the upper or lower edges of the iris and the closest edge of the image. The iris image should not exhibit effects of optical distortion including spherical aberration, chromatic aberration, astigmatism and coma consistent with standard optical design practices. The signal-to-noise ratio should not be less than 40 dB inclusive of any noise introduced by image compression techniques (ISO/IEC JTC 1/SC 37 N 504). [54]

Figure 25: US Coast Guard Biometric Equipment[55]

(4) U.S. Coast Guard "Biometrics at Sea"

[54] "Technical Advisory Group on Machine Readable Travel Documents" page 31, *ICAO TAG-MRTD/17-WP/16*, 1 June 07

[55] US Coast Guard Research and Development Center - http://www.rdc.uscg.gov/Portals/0/BTS2.pdf

In November 2006, the United States Coast Guard began fielding a device that collects biometric information from immigrants attempting to gain entry into Puerto Rico. The ruggedized biometric data capture device is built around a Hewlett-Packard iPaq Personal Digital Assistant (PDA). The PDA is housed in a plastic case that includes a digital fingerprint scanner and a camera. The biometric capturing device is then linked to a stand-alone laptop PC which extracts the data. The company responsible for the device is Identix.[56] Identix, which recently merged with Integrated Biometric Technology, assembled all the components, including its proprietary fingerprint capture software. Identix also worked with the Coast Guard to tailor the software to the service's needs. The device is capable of withstanding environmental extremes such as high temperature and humidity, ocean spray, and constant movement.

In order to gain access to a database of fingerprints, the US Coast Guard partnered with the Department of Homeland Security's United States Visitor and Immigrant Status Indicator Technology Program, better known as the US-VISIT Program. The US-VISIT Program uses a database of photos and two index finger fingerprints of individuals previously apprehended by border and immigration agents. The database is known as the Automated Biometric Identification System (IDENT). In May, the Coast Guard installed satellite technology on several cutters, which gave the agency access to all 90 million fingerprints in the IDENT database.

Biometric data consisting of two digital fingerprints and a digital photograph of the face and basic biographic information is collected from the immigrants by trained, uniformed USCG personnel. The data is then transferred to secure stand-alone laptops on the ships via USB cable and stored in encrypted files, which are then sent to US-VISIT as email attachments. The information is automatically erased from the handheld scanners when it is

56 Government Computer News, "Agency Award- Coast Guard and DHS, a touch of the finger stems the tide", http://www.gcn.com/print/26_26/45187-1.html. Last accessed 8 July 2008.

transferred to the laptop. It takes approximately two minutes to search all of US-VISIT's records.

Figure 26: USCG Use of Fingerprint Scanner

The US-VISIT program wrote software that opens the file, sends out a reply that it has been received, and begins the database processes where the matches are made. If there is a match, then the requisite information is sent back to the Coast Guard command center in San Juan. The data will then be compared to a subset of the IDENT database which includes known and suspected terrorists, aggravated felons, previous deportees, and recidivists from Caribbean countries. In the Coast Guard's application, the command center communicates back to the cutter regarding the status of the person and any precautions that might need to be taken[57] IDENT has proven the feasibility and scalability of capturing two prints and successfully identifying individuals with greater than 99% accuracy against a current population of 12 million.[58] Since all illegal migrants are informed that repeat offenders are subject to legal

57 FEDTECH, "Biometrics at sea". http://www.fedtechmagazine.com/article.asp?item_id=377&sv=related. Last accessed 8 July 2008.

58 Department of Homeland Security, "Ident Implementation for U.S. Visit", http://www.dhs.gov/xlibrary/assets/foia/US-VISIT_IDENTImplem.pdf. Last accessed 8 July 2008.

prosecution, the US Coast Guard has seen a decline in the number of migrant interdictions. In 2005, the number of interdictions was up to 10,000; in 2006, it decreased to 7,000. This measure of effectiveness can be attributed to the deterrent of the threat of prosecution.

(5) Proposed Solutions: The biometric solution for the purpose of identification and verification can be put together using COTS products, such as a fingerprint scanner, digital camera and laptop. The fingerprint biometric is selected here for its low cost and ability to perform the verification and identification tasks. The camera will be used to capture and store facial images of screened crew members. Below is a typical design of a self developed solution:

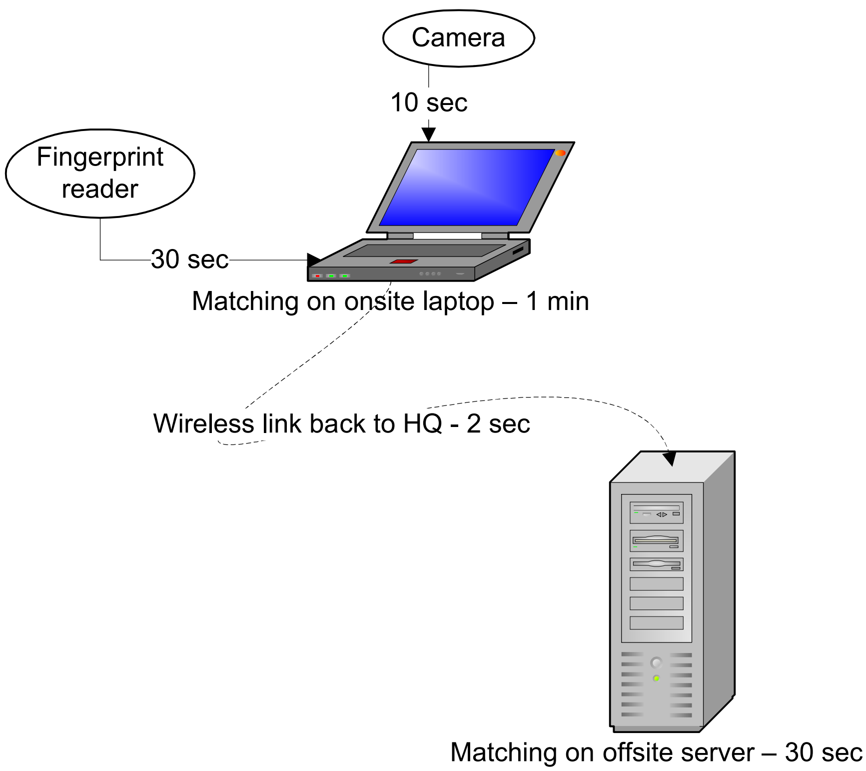

Figure 27: Basic Biometric Collection Solution with Sample Processing Times

Although this self-developed solution has the advantage of low cost COTS products, it is not as ruggedly designed as the USCG biometric device and might not be capable of operating in a diverse maritime environment. Additionally, it might not be as portable as other solutions. The overall system suitability, including but not limited to the reliability, availability, and maintainability will increase the overall lifecycle cost. This solution only provides the fingerprint biometric. It is not as reliable as the iris or retina biometric because its error rate is the highest among the three.

IBIS Mobile Identification System: The IBIS solution is provided by L-1 Identity Solutions. According to L-1 Identity Solutions, this solution uses “a modular handheld device that links via encrypted Bluetooth to any pre-configured, supported PDA”. Bluetooth operates at a frequency of 2.4 GHz and the range can vary from 1 to 100 meters depending on the particular device. Facial images of crew members can be captured and stored using the camera on the PDA. Figure 28 shows the IBIS mobile identification system. Appendix H includes the full product description from L-1 Identify Solutions.

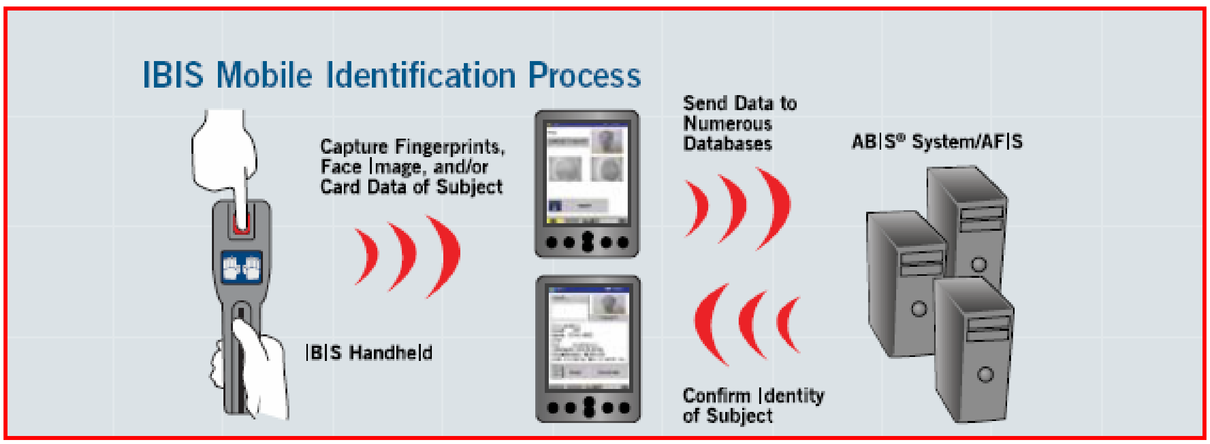

Figure 28: IBIS Mobile Identification Process

The advantage to this system is that it is portable and flexible in deployment. The primary disadvantage is that this solution only provides a fingerprint biometric. It is not as reliable as an iris or retina biometric as its error rate is the highest among the three. The performance of the PDA may not be as good as laptop computer.

(6) Hand-held Interagency Identity Detection Equipment (HIIDETM): This solution is also provided by L-1 Identity Solutions. According to

L-1 Identity Solutions, “the HIIDETM has an onboard processor and data storage capacity” and “utilizes the speed and accuracy of iris identification”. This device also includes a fingerprint scanner. Below is a picture of the device, the product description from L-1 Identity Solutions is attached as Appendix I.

Figure 29: Hand-Held Interagency Identity Detection Equipment

This is an integrated solution which provides both fingerprint biometric and iris biometric capability. This device is also integrated with a face capturing camera, where the image can be captured and stored in the database. It is a very portable device and could be easily transported by the boarding team to the suspect vessel. The primary disadvantage to this system is its high initial cost. Each system will cost approximately $10,000.

(7) Product Analysis/ Comparison: The three solutions are compared based on the following six criteria:

- Cost – The cost involved in the procurement stage.
- Supportability and Maintainability – This deals with all aspects of the product beyond the procurement stage.
- Reliability – The ruggedness and suitability of the product for the marine environment.

- Development Time – The product lead time before the solution is customized for our needs. This includes the time needed to interface with the communication devices for offline identification purpose.
- Portability – Ease of bringing the product for a boarding operation. Products will be judged based on weight, size and form factor (ease of carrying).
- Usability – Ease of use.

The result of the comparison is shown in Table 20 below. The highest rating possible for each criterion is 5.

Table 20: Weighting Criteria for Biometric Systems

	Self Develop	HIIDE	IBIS
Cost	(~USD1200) 5	(~USD10,000)2	(~USD1800) 5
Supportability & Maintainability	2	5	4
Reliability	2	4	4
Development time	2	4	4
Portability	3	5	4
Usability	1	5	3

Cost

1	>10000
2	<=10000
3	<=7000
4	<=4000
5	<=2000

Supportability & Maintainability

1	4 or more Components; Support from multiple vendors
2	2-3 Components, Support from multiple vendors
3	2-3 Components, Support from single vendor
4	Single Components; Support from multiple vendors
5	Single component; Support from single vendor

Reliability

1	Designed for indoor usage.
2	COTS. Designed for indoor usage.
3	Designed for outdoor usage.
4	Designed for harsh environment.
5	Mil Specs. Can be used in harsh environment.

Development Time (Assuming Unlimited Budget and Resource)

1	New Development ~ 48 months
2	Require exhaustive customization. Estimated Development Time ~24 months.
3	Require customization. Estimated Development Time ~12 months
4	Require minimal customization. Estimated Development Time ~6 months
5	Ready to use OOB.

Portability

1	Four or more Components; Bulky
2	Three Components; Less than 5.0lbs; Medium Sized.
3	Two Components; Less than 2.5lbs; Small Sized.
4	Single Component; Less than 5.0lbs; Medium Sized.
5	Single Component; Less than 2.5lbs; Small Sized;

Usability

1	Three or more separate interface to operate/ coordinate.
2	-NOT USED-
3	Two separate interface to operate/ coordinate.
4	-NOT USED-
5	Single MMI; Single device to operate/ coordinate. Ergonomic.

The Hand-held Interagency Identity Detection Equipment stands out in all categories. It is a highly customized product which seems to be most suited for our purpose. Since all features are integrated into a single piece component, it makes it highly portable and simplifies spares provisioning. The all-in-one interface is also cleaner and more usable.

(8) Recommendation: There are many types of biometrics; the proposed solution is based on a combination of a fingerprint biometric and/or iris biometric as they are more suitable for verification and identification purposes. All of the proposed solutions also include the feature of capturing and storing of photographs of screened crew members. The team recommends that the boarding team to be equipped with the HIIDETM biometric device. Despite the cost favorably leaning towards the self developed solution, the advantages of the HIIDE system are simply too overwhelming. More importantly, it is the better solution for our operational needs. Since the entire solution is encompassed in one product, the advantage of maintainability and supportability point in favor of HIIDE in terms of the total cost of ownership.

2. Macroscopic Intelligence

For the purposes of this report macroscopic intelligence collection refers to large scale area surveillance. The purpose of macroscopic intelligence collection is to begin to gain some degree of awareness to the locations of all the different ships in a given area as well as to gain the maximum amount of information that can be discerned from examining the exterior of a vessel.

Improvements in macroscopic intelligence collection are characterized by both the probability that a given target is detected and the resolution of which potentially identifying information can be discerned. For example, a picture that is of such low resolution that the lettering of a ship cannot be read is of less value than a picture of resolution sufficient to read the same lettering.

The challenge in collecting macroscopic intelligence becomes one of rapidly detecting all the contacts in a given area with a known probability of detection, as well as gathering identifying information about each of these. In this section, criteria for evaluation of surveillance systems is described. Two different surveillance systems were evaluated, and a final score given to the two basic systems.

a. Evaluation Criteria

Evaluation criteria for determining the effectiveness of a given surveillance platform were very similar to the criteria for the evaluation of overall MIO architectures, as was shown in chapter two of this document.

(1) Probability of detection: When evaluating different architectures, an overall generic category of “effectiveness” was assigned as the number one trait. In the case of evaluating macroscopic intelligence collection platforms, the probability of detection was given the highest consideration. This was given a higher consideration than other categories such as the resolution of potentially identifying information, because if a target is detected, then greater sensor time can be used to compensate for potentially low resolution identifying information. Resultant probability of detection for a given area is given by the following equation:

$$p_d = 1 - e^{\frac{-v \cdot W \cdot p_{d,sensor} \cdot t}{A}} \qquad (9.6)$$

Where in the equation, v is the velocity of the searching platform, W is the width of the swath covered, $p_{d,sensor}$ is the instantaneous probability of detection of a given sensor employed on a platform, t is time and A is the overall area being searched. [1] The area being searched was assumed to be a 300 x 500 nautical mile area as described in the scenario's section of this report. The swath width was calculated from the geometric height (h) of the mast and radius of the earth's curvature ($R_e = 6371km$) by equation(9.7).

$$d = \sqrt{2R_e h + h^2} \tag{9.7}$$

In the event the surveillance platform was airborne, then an operating altitude was assumed. A timeframe of one day was assumed for all further analysis in this section.

Equation (9.6) can be modified to show the cooperative effect of multiple identical sensors searching as shown in equation (9.8). This assumes that each sensor is given a non-overlapping segment to search and that all area to be searched was assigned to a sensor.

$$p_d = 1 - e^{\frac{-v \cdot W \cdot p_{d,sensor} \cdot t \cdot N}{A}} \tag{9.8}$$

Assuming an eighty percent probability of detection was desired, the number of sensors required to generate this result in one day was calculated by solving for N (the number of platforms) in equation(9.8).

$$N = -\frac{A \cdot \ln(1 - p_d)}{v \cdot W \cdot p_{d,sensor}} \tag{9.9}$$

(2) Amount of identifying information: The amount of information an analyst can use to specifically identify a detected target depends on a variety of different factors. Moonlit-spectral and RF emissions are also a factor in identifying a detected target. Because no identifying information can be gleaned from un-detected targets, this category was given a lower score than the probability of detection. It was given a higher score than any of the other criteria considered as it relates directly to the effectiveness of a sensor.

(3) Bandwidth: If a sensor of some form was able to detect a target and collect identifying information on the same target, this would be useless unless it could transmit the information to a platform capable of either retransmitting or acting on the information.

(4) Survivability: A sensor that was intended to maintain a large scale macroscopic view of a large area needs to be able to survive weather as well as any likely enemy action. If a sensors delicacy or susceptibility to attack causes it to break (or be attacked), then it will not be able to detect or identify targets.

(5) Cost: If a sensor is relatively inexpensive, then a large number of them can be purchased and employed with relative impunity. This criterion has to be given equal weight to survivability. If a large number of inexpensive yet easily-attacked sensors can produce equivalent surveillance to one large (yet expensive) sensor, then the performances of both sensors will be equivalent. The survivability/cost tradeoff is given less consideration than the actual ability of a sensor to perform its mission independent of it being attacked or funded. Table 20 identifies the relative weights given to each of the sensors.

Probability of Detection	10
Amount of Information	7.5
Bandwidth	5
Survivability	2.5
Cost	2.5

Table 21: Relative weights for comparing macroscopic surveillance platforms

b. Robotic Sailboat

The robotic sailboat or “Autonomous Unmanned Surface Vessel (AUSV)” as manufactured by Harbor Wing Technologies, Inc is the principle form of an autonomous surface vehicle considered in this report. Appendix H contains excerpts from a briefing generated by Harbor Wing Technologies for use in this report.

The purpose of considering the robotic sailboat is to answer the macroscopic aspects of the “collect maritime intelligence” requirement of the original problem.

(1) Probability of detection - 1: With a mast height of sixty meters, the resultant horizon distance is (W) 14.9 nautical miles (nm). The craft moves at a velocity of five to seven knots (depending on weather conditions). For this analysis, seven knots is assumed. As the description of the robotic sailboat's camera suggests that it is very high resolution, a very generous sensor probability of detection of 100% is assigned. In order to cover the larger area defined in the scenarios, 97 sailboats are required. The very low probability that a robotic sailboat will be able to move around enough to cover and effectively search enough of an area to find a target of interest results in a score of one (out of ten) being assigned to this category. While recognizing that this gratuitous number of robotic sailboats is dependent on comparisons of random search areas, it is important to note that the relative orders of magnitude required to obtain a satisfactory result.

(2) Amount of identifying information - 6: Assuming a target moves within the detection range of the sailboat, it is assumed that for the length of time the sailboat will be in range of its target that the sailboat will be able to collect a good deal of information as can be observed from near the waterline. It will not be able to generate overhead imagery of a target like an aircraft could. Given the relative speed between a slow moving sailboat with limited maneuverability and a merchant vessel (which is likely going twice as fast), the robotic sailboat will only be able to collect video of one side of the detected vessel.

(3) Bandwidth - 2: In order to utilize any of the information obtained by the robotic sailboat, the information must be transmitted to a platform that is either capable of retransmitting it, or a platform that is capable of independently acting on the information. Since the horizon distance for the robotic sailboat is only 14.9 nm, the odds of a unit capable of acting on the intelligence being present within the line of sight communications range of the robotic sailboat is very small. Therefore, the robotic sailboat will have to transmit the communication to a satellite for further relay onwards to a unit that can relay

the information or otherwise directly act on it. The free space path loss between the satellite and the robotic sailboat will severely diminish the link margin. In order to get an equivalent degree of bandwidth, a large gain on an antenna will be required. Since the form-factor of the sailboat is not conducive to large dishes (approximately six feet) that are gyro stabilized and able to communicate with a geostationary satellite, it is unlikely that the sailboat will be able to get sufficient bandwidth to relay the amount of information it could collect on detected targets. Some information could be transmitted using omni-directional satellite antennae; however, streaming video will be impossible.

(4) Survivability -1: The robotic sailboat is weakest in this area. Although its top speed is seven knots (in good winds), in the absence of winds, the sailboat is immobile. Should the sailboat be operating in a densely packed shipping channel, the sailboat will be unable to maneuver to avoid oncoming traffic and could very easily be destroyed by merchant traffic. Furthermore, the sailboat is defenseless from the hostilities of either nation states or individuals acting out of an anti-American malice. Given that it is solar powered and has large exposed surfaces, automatic weapons fire from an AK-47 would be severely damaging. Lastly, in addition to being defenseless, the sailboat has inadequate speed to escape a given threat.

(5) Cost - 1: The robotic sailboat costs \$2.2 million (2008) dollars each as quoted by Harbor Wing Technologies, Inc.

c. Generic UAV

(1) Probability of detection - 7: If it is assumed that a UAV can travel one hundred knots at an altitude of one thousand feet and have a fifty percent chance of detecting a target on the ground, then fourteen UAVs are sufficient to conduct a random search of the same area described for the robotic sailboat in a twenty four hour time period. As this is seven times more efficient than the robotic sailboat, a score of seven is assigned.

(2) Amount of identifying information - 10: The UAV has the capability to maneuver to see all sides (including the top) of a detected target. As it moves relatively fast, it can revisit frequently. It has the option to fly by more frequently to get closer to a target as the velocity of a UAV is likely many times greater than the velocity of any given target vessel.

(3) Bandwidth - 8: Though the UAV's payload is more constrained than the robotic sailboat, the UAV has the option to climb to a higher altitude at which point its footprint is significantly larger. Once at altitude, the probability that a US asset capable of either relaying the UAV's information or directly acting on it is substantially larger (especially considering that the UAV was probably launched from the ship).

(4) Survivability – 10: The UAV is capable of maneuvering away from threats as it will move significantly faster than any surface vessel. Its relatively small size will make it substantially more difficult to shoot using crew-served weapons than is the case for the robotic sailboat.

(5) Cost - 10: UAVs can be as inexpensive as $100,000

d. Comparison

The scores and resultant values of a generic UAV and a robotic sailboat are detailed in Table 22.

	Weight	Sailboat	UAV
Probability of Detection	10	1	7
Amount of Information	7.5	6	10
Bandwidth	5	2	8
Survivability	2.5	1	10
Cost	2.5	1	10
Total	27.5		
		2.6	8.6

Table 22: Comparison of scores and weighted results

The sharp contrast in scores shows that the robotic sailboat is a fundamentally flawed paradigm in conducting large scale area surveillance. UAV's of any form will always be greatly superior as a direct result of their relative velocities, ability to maneuver, and relatively low cost.

Reference

[1] "Biometrics Comparison Chart", National Center for State Courts, http://ctl.ncsc.dni.us/biomet%20web/BMCompare.html#aspects

[2] "How does a Retinal Scan Work?", wisegeek, **http://www.wisegeek.com/how-does-a-retinal-scan-work.htm**

[3] "Technical Advisory Group on Machine Readable Travel Documents" page 25 to 31, *ICAO TAG-MRTD/17-WP/16*, 1 June 07

[4] "Privacy Impact Assessment for the U.S. Coast Guard 'Biometrics at Sea' Mona Passage Proof of Concept", 1 November 2006

[5] "IBIS Mobile Identification System", L-1 Identity Solutions, http://www.l1id.com/images/stories/solutions/ibis_datasheet.pdf

[6] "Hand-Held Interagency Identity Detection Equipment", L-1 Identity Solutions, http://www.l1id.com/images/stories/Products/Datasheets/hiide.pdf

b. Non-Networked Computer Exploitation

Non-networked computer exploitation will generally involve two steps: The first step involves gaining access to the system to access the file system, and the second to carry out the exploitation, which is the search for the information of interest.

The first step will be trivial if the crew of the ship provides the boarding team with an account on the system. Without it, if the boarding team has the required rights within the legal limits of the law, they may attempt to access the system file directories via an auxiliary boot-up disk. The hard disk might have to be removed for cloning or for mounting on a separate system for analysis.

The second step involves searching the system for relevant information. This step can prove to be extremely difficult and time consuming. If the data is encrypted, assuming the crew of the ship does not provide the decryption key, cracking the key or breaking the algorithm is required to get to the files. He or she will also need to define a set of search criteria. In addition, quoting Professor Garfinkel's article on DOcument & Media EXploitation (DOMEX), the work of deep searching will probably involve more than pure exploring and opening discovered files on the system as that may miss a big deal of information. On top of deep searching, analysis and verification of the findings may be required.

> As evidenced by these and countless other cases, digital documents and storage devices hold the key to many ongoing military and criminal investigations. The most straightforward approach to using these media and documents is to explore them with ordinary tools—open the word files with Microsoft Word, view the Web pages with Internet Explorer, and so on.
>
> Although this straightforward approach is easy to understand, it can miss a lot. Deleted and invisible files can be made visible using basic forensic tools. Programs called carvers can locate information that is not even a complete file and turn it into a form that can be readily processed. Detailed examination of e-mail headers and log files can reveal where a computer was used and other computers with which it came into contact. Linguistic tools can discover multiple documents that refer to the same individuals, even though names in the different documents have different spellings and are in different human languages. Data-mining techniques such as crossdrive analysis can reconstruct social networks—automatically determining, for example, if the computer's previous user was in contact with known terrorists. This

> sort of advanced analysis is called DOMEX, the intelligence practice of document and media exploitation.

In summary, it is difficult to gauge the time needed for the exploitation as it is dependant on a myriad of factors: State of system to exploit (OS flavor, security state); State of information (encrypted, non-encrypted); Skill/Experience of Forensic Expert; Cooperation of ship crew; Depth of exploitation (Pure surface search for documents or going deep, DOcumentation & Media EXploitation (DOMEX))

There is also a chance factor involved. Analysis of the retrieved information will take time and effort and the entire exploitation process may take from a couple of hours up to a few weeks. The time needed is unpredictable and there is high chance that the work may not be completed within a short time. Time is certainly required for thorough analysis. DOMEX is also a new field and few people can judge how successful the technique is or will be, but it certainly does not seem to be guaranteed achievable when given a time and resource constraint. This point is again supported by the same article by Prof Garfinkel.

> For example, in 2005 the United Kingdom passed legislation extending the time that terrorism suspects could be held without being charged from 14 days to 90 days, in part because the two weeks provided by the previous terrorism law did not provide sufficient time for the forensic analysis of a typical hard drive.

The conclusion from the paper was that "a high-confidence automated DOMEX system might give police the tools they need to clear a suspect in days, if not hours," but automated DOMEX systems are still very much under research.

(1) Skill Set Required: The Forensic Expert will require a wide range of skills to have a fair chance of successfully exploiting the system including, but not limited to: OS specific skills to hack into the system on board (Nobody can predict the OS that will be encountered); cracking encrypted files; domain Knowledge for information to be sought; analytic skills; forensic

Investigator skills. He or she will need to be extremely efficient, meticulous and be able to perform all that under the constraint of time and tools (probably better equipped inside the lab).

(2) Recommendations: Time required to perform non exploitation can widely vary and the skill set required is diverse depending on the system on board. The team feels that it is most optimal to clone the disk in question or to seize the system back to perform an offsite analysis in the comfort of the forensic lab, and support of more forensic staff. Only when there is intelligence to believe that doing the forensics while on-board is more fruitful would the boarding team need to take a forensic expert along to attempt to do some hacking in real time.

<u>Reference</u>

[1] Simson L. Garfinkel, "Document and Media Exploitation," http://www.simson.net/clips/academic/2007.ACM.Domex.pdf , ACM Queue, November/December 2007, Pg 1 - 10

VIII. INTERCEPT

A. INTRODUCTION

The action of boarding a vessel (regardless of level of compliance of the target crew), requires the team of people conducting the boarding to assume a number of inherent risks. Although the preponderance of analysis in this report considers compliant cases, this analysis is targeted at the conditions where compliance becomes variable. From the outset of an attempt to board, the target ship's crew may be hostile to the idea of boarding or even making efforts to prevent the boarding team from getting on board. Alternatively, the target crew could give all appearances of compliance but then change their stance once contraband is located. This report considered a few possible approaches to ensuring the crew of the target vessel remains compliant, or that a hostile target crew becomes compliant.

In order to provide the MIO task force with other options beyond the destructive firepower that a DDG can bring to bear, unmanned systems are considered here. Proposed unmanned systems will be able to accomplish missions such as communications relays, escorting of suspect vessels, a show of force (deterrent) as well as warning and disabling fires. This section attempts to analyze the effectiveness of various unmanned systems in performing these rolls.

B. APPROACH

As unmanned systems will be used for the first time for MIO, a new Concept of Operation (CONOPS) will have to be determined. Thereafter, suitable unmanned systems will be selected based on the overall MIO CONOPs.

For the selection processes contained herein, the Analytic Hierarchy Process (AHP)[59] was used to evaluate all suitable candidates and select the optimal platform based on an evaluation of set criteria. AHP, developed by Thomas Saaty, provides a proven, effective means to deal with complex decision making and can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria and expediting the decision-making process. It is a method to derive ratio scales from paired comparisons. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value.

C. PROBLEM DEFINITION

Conventional boarding operations can have many complications. Current operation requires a manned helicopter to support the boarding crew. However, the endurance for the helicopter is limited and refueling is required back at the mother ship. This may lead to a level one vessel (compliant) turning into a level four (opposed) if the target ship's crew believes that support from the mother ship will not be forthcoming. With unmanned systems, the long endurance capability and sensors onboard will allow the mother ship to maintain constant surveillance on the boarding operation.

More importantly, the unmanned systems will provide precision strike capability which is potentially lacking from the parent ship. Precision strike capability from a UAV can disable the suspect vessel should the need arise and non-lethal weapons can be used by an unmanned surface vehicle (USV) to disarm the crew onboard the suspect vessel and to remove any potential lethality threats against the boarding crew.

[59] ***Analytical Hierarchy Process (AHP)*** *is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives. The concept of AHP was developed, amongst other theories, by* ***Thomas Saaty****, an American mathematician working at the University of Pittsburgh.*

D. FUNCTIONAL DECOMPOSITION

The functional decomposition is broken down into two categories: Intercept and Disable.

1. Intercept

The intercept function is composed of: intercept of level one through level four adversaries and the protection of the boarding crew.

2. Disable

The disabling function is composed of: determine weapons availability, match weapons to Targets, determine weapons payload, utilize appropriate weapon and assess battle damage.

E. INTERCEPT OPERATION

Upon confirmation of intelligence on the location of the suspect ship the boarding vessels will begin the intercept on the suspect ship. A UAV and a USV will be utilized to carry out the intercept while the boarding vessels and crew are put out of harm's way. The entire intercept operation is elaborated in this section.

Rules of Engagement (ROE) are assumed to be completely permissive for the purposes of this analysis. Specifically, shows of force, warning shots, employment of non-lethal weapons, and disabling fire against non-compliant vessels are all allowed. In actual employment of said systems, the degree to which the features of recommended platforms can be employed may be limited based on what the combatant commander sets in the ROEs.

1. Receipt of Mission Orders

The boarding operation will commence upon the receipt of mission orders. The phases involved in the boarding operation include: the deployment of organic intelligence-gathering equipment, approach to the suspect ship, transition state during boarding, stand-off fire support and retrograde. The approach and Rules of Engagement (ROE) for levels one through four vary, depending on the condition and state of the suspect vessels.

2. Level 1: Compliant

Compliant intercept procedure involves an ISR UAV and an USV. The intercept procedure begins with the launching of the ISR UAV (assuming it is not already on station) and the USV. The ISR UAV and USV will assess the routes of approach by the boarding vessel and determine the most appropriate embarkation point. The UAV is to maintain loitering position over the suspect ship for the duration of the operation.

The suspect ship will be requested to prepare for embarkation on both sides of the ship in order to allow flexibility to the boarding operation and maintain an element of tactical surprise.

The boarding vessel will maintain a safe distance abaft the beam from the suspect ship until all information has been confirmed and the suspect vessel is prepared to be boarded. The USV will maintain the same position opposite the boarding vessel.

Once the suspect vessel has been confirmed to be compliant, it will be escorted to the area in which the physical boarding will take place.

3. Level 2 and 3: Non-Compliant (Low and High Free Board)

Non-compliant intercept procedure involves an armed UAV, an ISR UAV, and an USV. The ISR UAV, armed UAV and USV are launched at the same time. The suspect vessel's crew will be requested to assemble in the deck for visual mustering by the UAV. The UAV will assess the routes of approach by the boarding vessel and the embarkation point. The UAV will continue to maintain loitering position over the suspect ship for the entire duration of the operation.

All three unmanned systems will provide a show of force that is intended to convey a higher level of seriousness by the boarding team. In the event of continued non-compliance, a verbal warning will be issued in order to establish the intent of the suspect vessel. If the suspect vessel continues the non-compliant action, the USV will fire a warning shot(s) across the bow of the suspect vessel in order to coerce the vessel into a compliant state.

The USV, equipped with both lethal and non-lethal weapons, is to maintain a forward position on the suspect vessel in case there is an attempt of escape. In this event, the USV will give the parent ship the option (depending on applicable ROEs) to utilize non-lethal or lethal weaponry to prevent or hinder the escape of a target vessel.

Information gathered by the unmanned vehicles will be processed and the threats will be determined from the information gathered. The USV will maintain an adequate communication linkage back to the parent ship in order to allow for timely exploitation of information gathered by the USV.

If compliance is not achieved following warning shots, disabling fire from the armed UAV will commence in order to stop the suspect vessel. If compliance is then achieved, the boarding team will approach the suspect vessel from abaft the beam and begin the physical act of boarding the suspect vessel.

After embarkation of the boarding team, both UAVs and USV will remain on station to provide air cover, communication relay, and fire support.

4. Level 4: Opposed

Level four intercepts require the same amount of resources as the level two and three scenarios. There is also a likelihood that a level two or level three boarding could develop into a level four boarding.

The deployments of the UAV and USV will be the same as that described for level two and level three intercepts.

If the suspect ship displays hostile intent and does not change action based on a verbal warning, non-disabling warning shots will be fired from the USV.

If signs of hostility continue, incapacitating weapons mounted on the UAV and USV will be employed to disable the propulsion system of the suspect vessel.

Assessment will be made using sensors onboard the unmanned system to determine the threat level. If level one boarding scenario has been achieved, the boarding team will commence the boarding procedure.

5. Communications

Due to the boarding teams' radio system limitations, the unmanned system can serve as a communication relay to the mother ship.

Real time intelligence from the UAV will be viewed by the boarding team members on the boarding vessel. The information will be processed and simultaneously relayed back to the boarding team. This information will be specific to on-deck activities that could pose a threat to the boarding team conducting the search on the suspect vessel.

F. DISABLE

Based on the proposed Concept of Operations, a minimum of one armed UAV, one ISR UAV and one USV are needed to support one MIO mission. Although guided munitions launched from the parent ship have been considered, these munitions do not have the responsiveness and flexibility of guided munitions fired from unmanned systems in closer proximity to the target vessel. The UAV and USV will have surveillance, identification, force protection, targeting, and precision attack capabilities. The platforms are equipped with lethal and/or non-lethal weapons. Table 23 shows the matrix of the type of weapon systems to be carried by the platforms.

Platform	Target	Weapon Type
UAV	Platform	Non-Lethal (N/A)
		Lethal
USV	Personnel	Non-Lethal
		Lethal
	Platform	Non-Lethal
		Lethal

Table 23: Matrix of Weapon Systems for Platforms

There are several platforms currently available to the defense market that may be suitable for deployment in MIO missions. This chapter deals with the evaluation and selection process for the platforms and selected weapon system payloads.

As discussed in the "approach" section earlier. The Analytic Hierarchy Process was used for determining the platforms and selected weapons system payloads.

1. Determine Platforms/Weapon Systems Availability

It is recommended to obtain from the defense market suitable platforms that will meet the five year scoping requirement. It is also recommended to use existing weapon systems that can be integrated onto the platform. However, the integration of new weapon systems can still be conducted if the weapon system is assessed to be tested, fielded, and operational.

a. Selection of UAVs

The operational requirements for the UAV platform are as follows:

(1) Conduct surveillance, force protection, targeting and precision attack capabilities.

(2) Launch and recovery using vertical take off and landing (VTOL).

(3) Minimum external payload of 100 Kg.

(4) Mission radius not less than 30nm.

Table 24 shows the various UAVs that were studied to determine the suitability for deployment. Several UAVs cannot meet the operational requirements due to reason given in the remark column. Three UAV's (MQ-8B Fire Scout, A160 Hummingbird and Seamos) meet the requirements and were selected using AHP. This process was performed using a commercial software known as the Expert Choice. AHP analysis and technical specifications can be found in Appendix K.

Platform	Selected	Not Selected	Remarks
A160 Hummingbird	√		
Cypher/Cypher II (Dragon Warrior)		**X**	Limited payload (25 kg)
Hermas		**X**	Not VTOL capable
MQ-8B Fire Scout	√		
Pioneer		**X**	Not VTOL capable
Sentry		**X**	Not VTOL capable
Seamos	√		
Vigilant Observer		**X**	Limited payload (8kg), short mission radius (15+km)

Table 24: List of UAVs

Figure 30: MQ-8B Fire Scout (U.S.)

Figure 31: A160 Hummingbird (U.S.)

Figure 32: Seamos UAV (Germany)

The evaluating criteria used in AHP analysis are External Payload (weight), Endurance, Capabilities (existing and projected), Interoperability, Ease of Integration and Program Risk. The description and weighting of the evaluating criteria can be found in Appendix K.

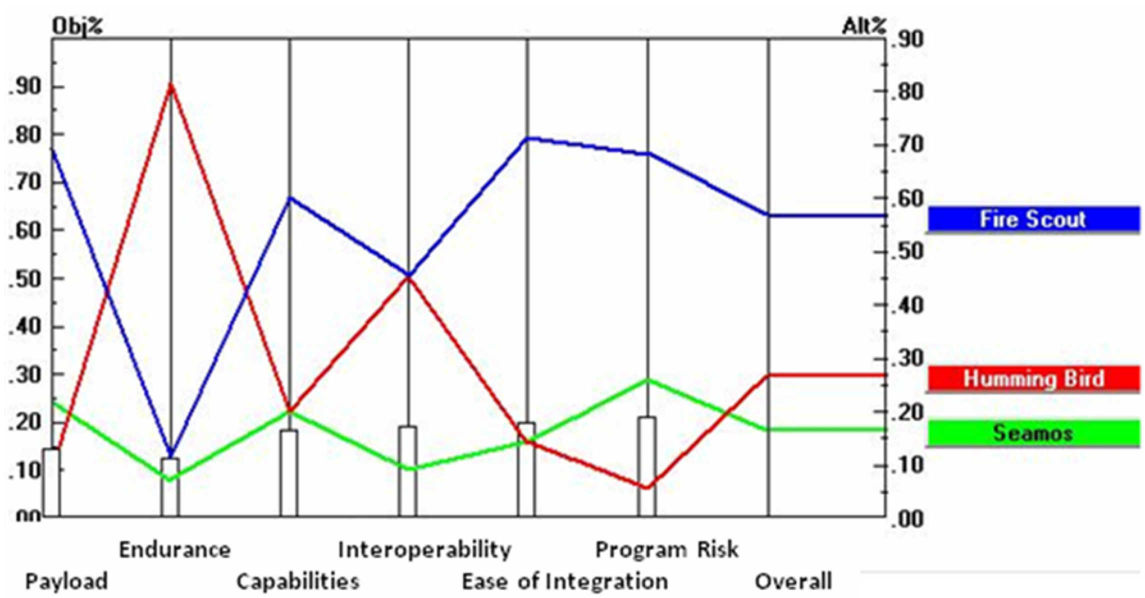

Figure 33: AHP's results for UAV Selection

The final UAV selection as described by the global weighted evaluation gives the **Fire Scout as the best option at 56.7%.**

b. Selection of USVs

The operational requirements for the UAV platform are as follows: Conduct surveillance, targeting and precision attack capabilities:

(1). Prepare the waterspace for boarding.

(2). Provide protection for boarding crew.

(3). Minimum external payload of 1500lbs.

(4). Mission radius not less than 30nm.

Table 3 showed the various USVs that were studied to determine the suitability for deployment. Several USVs cannot meet the operational requirements due to reason given in the "Remarks" column in Table 3. 3 USVs (Protector, Spartan and Silver Marlin) meet the requirements and were down selected for AHP selection process. Technical specifications for the three platforms can be found in Appendix L.

Platform	Selected	Not Selected	Remarks
Protector (Israel)	√		
Silver Marlin (Israel)	√		
Sea Fox (US)		**X**	Limited payload. Experimental platform
Sea Owl (US)		**X**	Limited payload. Jet ski chassis
Sentry (UK)		**X**	Limited payload. Intended as harbor security vehicle.
Spartan (US)	√		
Rodeur (France)		**X**	Limited payload

Table 25: List of USVs

Figure 34: Protector USV (Israel)

Figure 35: Silver Marlin (Israel)

Figure 36: Spartan USV (US)

The evaluating criteria used in AHP analysis are external payload (weight), endurance, capabilities (existing + projected), interoperability, ease of integration and program risk. The description and weights of the evaluating criteria can be found in Appendix L.

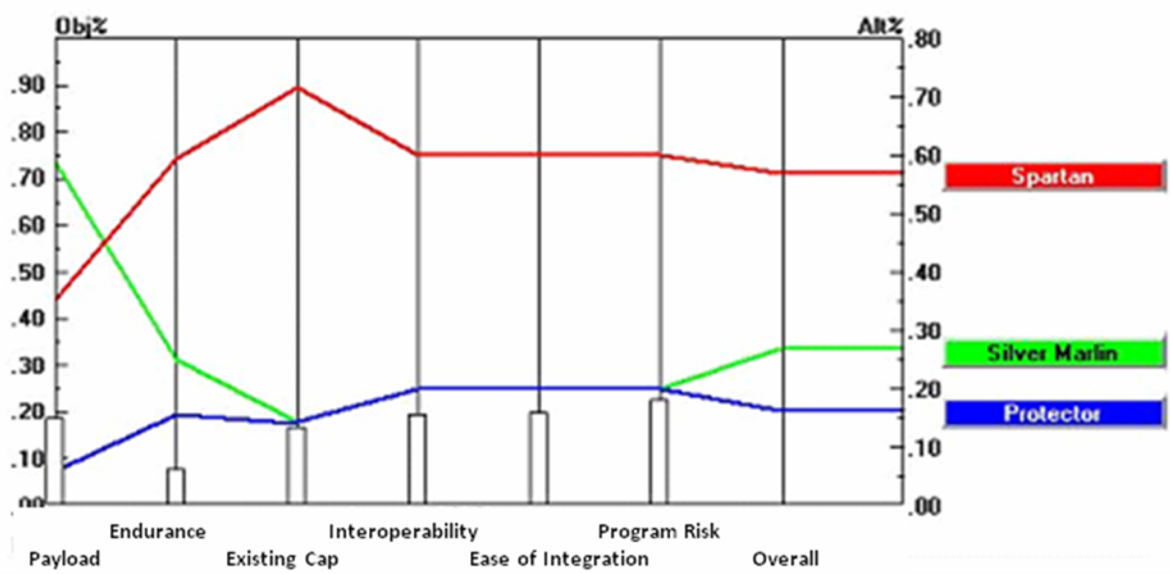

Figure 37: AHP's results for USV Selection

The final USV selection as described by the global weighted evaluation gives the **Spartan the best option at 56.9%**.

c. External Weapons Payload Selection

The Fire Scout and Spartan platforms shall be equipped with lethal and/or non-lethal weapons for the mission. Lethal weapons are intended to intimidate, disable and destroy the intended target while non-lethal weapons are intended to temporary incapacitate potential threat persons. The non-lethal weapons offer alternatives to the commander and allow a more proportional response to a perceived threat.

To minimize integration efforts and funding, weapon systems that are already integrated or planned for integration on the Fire Scout UAV and Spartan USV will form the basic payload for the mission.

d. Lethal Weapons Selection

Currently, the only lethal weapon on the platform is the GAU-17 Gatling Gun integrated onto the Spartan USV. However, there are programs on-going to integrate precision strike weapon on both Fire Scout (Hellfire) and Spartan (Hellfire & Javelin). With sufficient support and funding, the Hellfire and Javelin are likely to be ready for operation with the platforms in the next 5 years.

<u>AGM-114M Hellfire Missile</u>. There are plans to integrate the Hellfire on both the Fire Scout UAV and Spartan USV. The Hellfire missile can be used to engage and destroy the target vessel at standoff range of more than 8km. The missile has a semi-active laser seeker and a blast fragment warhead. The missile can operate in a co-operative mode where the laser designator does not need to be on the launch platform, but can be located several km away.

<u>Javelin Missile</u>. There are plans to integrate the Javelin missile on the Spartan USV. Similar to the Hellfire, the Javelin is an anti-armor missile capable of engaging and destroying the target vessel at standoff range although the maximum standoff range for Javelin (2.5km) is shorter than the Hellfire (8km). The missile has an imaging infrared seeker, shorter minimum range and lighter in weight compared to the Hellfire. While the Javelin missile would be incapable of

destroying a target vessel, its precision strike capability might enable it to be guided towards a more vulnerable area of a target ship (i.e., destroying the target ship's rudder or pilot house).

GAU-17 (7.62mm) Gatling Gun. The GAU-17 is integrated on the Spartan USV. The gun can be used to fire warning shots and provide covering fires for the boarding team when required. The gun fires 7.62mm ball, tracer or Sabot launched armor piercing (SLAP) rounds and the typical engagement range for the gun is about 2.2km. The technical specification can be found in Appendix M.

e. Non-Lethal Weapons Selection

There is no requirement for non-lethal weapon on the Fire Scout UAV in the current concept of operations. Presently, there is also no non-lethal weapon integrated on the Spartan USV platform but the following classes of non lethal weapons have been considered for deployment on the Spartan USV to enhance existing operations:

Against Platform. It is recommended that the USV be fitted with the MK 11 static running gear engagement system (RGES) against evasive targets. The RGES (about 60 ft of line) will deploy the system ahead of the fleeing boat from the USV. When the fleeing vessel runs over it, the RGES will become entangled in the propellers disabling it.

Against Personnel. Three types of weapons were considered for integration with the USV and they are evaluated using AHP:

(1) High Pressure Water Cannon System (WCS). Water cannons are devices that shoot a high-pressure stream of water. Typically, water cannons can deliver a large volume of water, often over dozens of meters / hundreds of feet. WCS provides enough force to restrain an average sized human at this distance and are typically used in riot control.

(2) Remote Long Range Acoustic Device (LRAD-R). LRAD-R is a long-range hailing and warning directed acoustic beam device. Some devices project audible, ultrasonic or infrasonic sound frequencies and may cause pain/discomfort, nausea, disorientation to personnel.

(3) Anti-Traction Mobility Denial System (MDS). The MDS is a non-hazardous chemical spray system that spreads a highly slippery, viscous gel to inhibit the movement of individuals or vehicles on treated surfaces such as asphalt, concrete, grass, and wood. The gel can be distributed over a wide area by a vehicle-mounted system or /and around buildings from a portable unit operated by an individual.

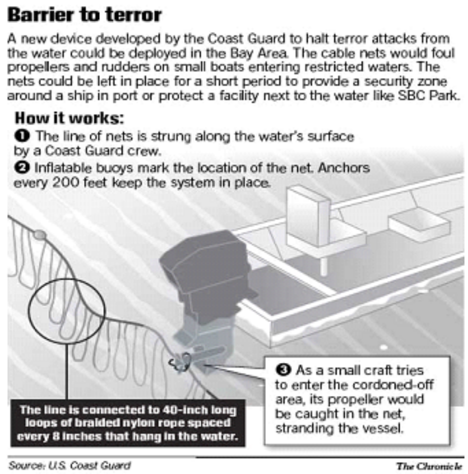

Figure 38: MK11 Static RGES

Figure 39: Water Cannon System

Figure 40: Mobility Denial System

Figure 41: LRAD-R

The evaluating criteria used in AHP analysis were namely; Ease of Integration, Equipment Operating Range, Ease of Operation, Weapon Effectiveness and Maintainability. The description and weights of the evaluating criteria can be found in **Appendix N**.

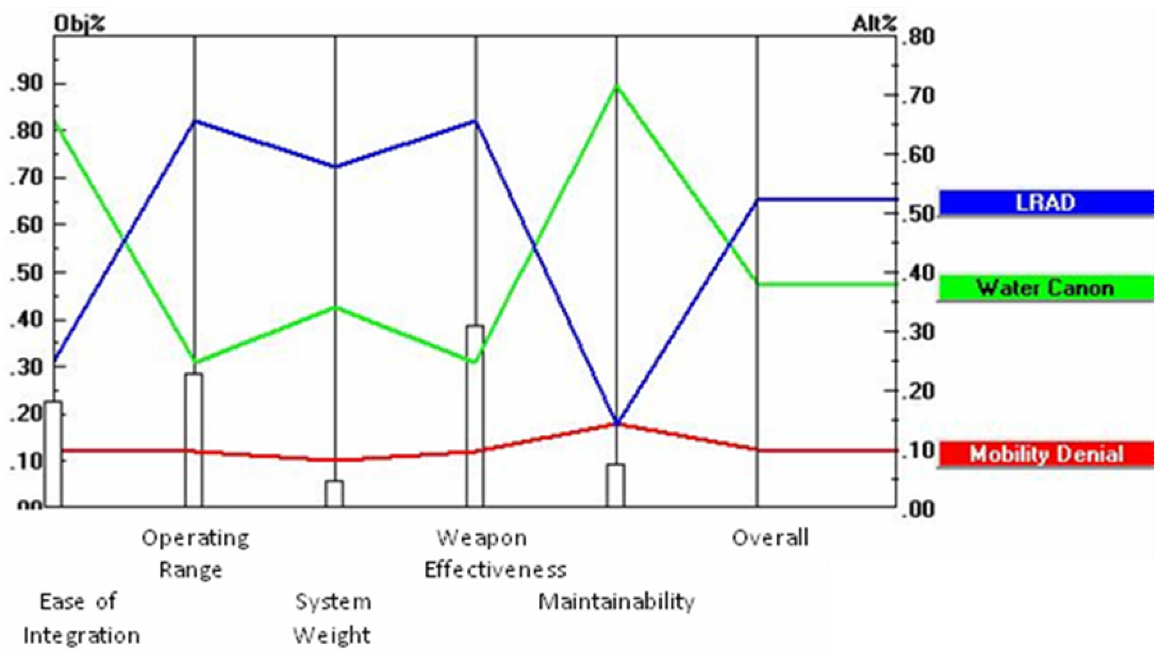

Figure 42: Non-Lethal Weapon Selection

From the AHP evaluation, the LRAD-R is selected as the most suitable (52.3%) weapon type to meet the objective for mounting on the USV platform.

Manufactured by American Technology Corporation, the LRAD-R is highly directional and is able to clearly communicate instructions and warnings well beyond 500 meters. The system can also transmit powerful deterrent tones to influence behavior or determine intent of crew onboard the suspect vessel. In addition, the LRAD-R can be operated remotely enabling system operators to respond to security threats from a safe environment.

2. Matching Weapons to Target

Based on the selected weapon systems, the matrix of weapons and intended targets are tabulated in Table 26.

<table>
<tr><th>Platform</th><th>Target</th><th>Weapon Type</th><th>Weapon System</th></tr>
<tr><td rowspan="4">Fire Scout</td><td rowspan="2">Personnel</td><td>Non-Lethal (N/A)</td><td></td></tr>
<tr><td>Lethal</td><td>Hellfire</td></tr>
<tr><td rowspan="2">Platform</td><td>Non-Lethal</td><td></td></tr>
<tr><td>Lethal</td><td>Hellfire</td></tr>
<tr><td rowspan="4">Spartan</td><td rowspan="2">Personnel</td><td>Non-Lethal</td><td>LRAD 1000</td></tr>
<tr><td>Lethal</td><td>7.62mm Gun</td></tr>
<tr><td rowspan="2">Platform</td><td>Non-Lethal</td><td>MK 11 static RGES</td></tr>
<tr><td>Lethal</td><td>7.62mm Gun
Hellfire or Javelin (future)</td></tr>
</table>

Table 26: Platform-Weapon-Target Matrix

3. Configuration List

The MQ-8B UAV can be configured with external payloads as listed in Table 27:

<table>
<tr><th>Mission</th><th colspan="2">Equipment</th></tr>
<tr><td rowspan="2">ISR</td><td>ISR[60]</td><td>EO/FLIR Systems (Brightstar III)
Laser Range Finder</td></tr>
<tr><td>Weapon</td><td>Nil</td></tr>
<tr><td rowspan="2">Disabling</td><td>ISR</td><td>EO/FLIR Systems (Brightstar III)
Laser Range Finder</td></tr>
<tr><td>Weapon</td><td>Hellfire Missile (planned)</td></tr>
</table>

Table 27: MQ-8B Fire Scout Configuration

[60] Intelligence, Surveillance and Reconnaissance

The Spartan USV can be configured with external payloads as listed in Table 28.

Mission	Equipment	
ISR, Disabling, Warning Fire, Support Fire	ISR	EO/FLIR Systems Chemical/Biological Detector Laser Range Finder
	Lethal	GAU-17 7.62 Gun Hellfire Missile (future) or Javelin Missile (future)
	Non-Lethal	Long Range Acoustic Device (LRAD) MK11 Static RGES

Table 28: Spartan USV Configuration

4. Equipment List

The recommended equipment list for single mission is tabulated below in Table 29.

Description	Equipment	Qty
Platform	Fire Scout UAV	2
	Spartan	1
Lethal Weapon	Hellfire (UAV)	2
	Hellfire / Javelin (USV)	2
	GAU-17 Gatling Gun	1
	7.62mm rounds	1,500
Non-Lethal Weapon	LRAD	1
	MK11 Static RGES	1
Target Acquisition	Brightstar III	2
	Laser Range Finder	3
Others	Chemical/Biological Detector	1

Table 29: Equipment List

5. Assess Battle Damage

The platforms are equipped with both camera and IR systems that transmit real-time images back to the mother ship. The operator on-board the mother ship can then assess the damage through information obtained from these sensors.

G. WEAPON COMPATIBILITY

1. Compatibility

Compatibility study between the DDG 51 - Arleigh Burke Class Aegis Guided-Missile Destroyer and MQ-8B Fire Scout will be discussed in this chapter.

2. Description of DDG 51 – Arleigh Burke Class Aegis Guided-Missile Destroyer

The DDG 51 class is a multi-mission guided missile destroyer designed to operate independently, or as a unit of Carrier Strike Groups (CSG), Expeditionary Strike Groups (ESG), and Missile Defense Action Groups in multi-threat environments that include air, surface, and subsurface threats. These ships will respond to Low Intensity Conflict/Coastal and Littoral Offshore Warfare (LIC/CALOW) scenarios as well as open-ocean conflict providing or augmenting power projection, forward presence requirements, and escort operations at sea.

Figure 43: DDG 51 - Arleigh Burke Class Aegis Guided-Missile Destroyer

Several upgrades and modification were made to the DDG 51 and Flight IIA was introduced. Engineers added a helicopter hangar with one anti-submarine helicopter and one armed attack helicopter to the Destroyer.

3. Flight IIA

Introduction of Flight IIA is critical to littoral war fighting effectiveness as it includes embarked helicopters (SH-60R), an organic mine-hunting capability and the introduction of area theater ballistic missile defense capability to protect near coastal air-fields and seaports essential to the flow of forces into theatre in time of conflict.

The first 28 Arleigh Burke-class destroyers have a helicopter deck but no hanger or embarked helicopters. Ships in production, such as the Flight IIA, have landing and hangar facilities for operation of two SH-60Rs.

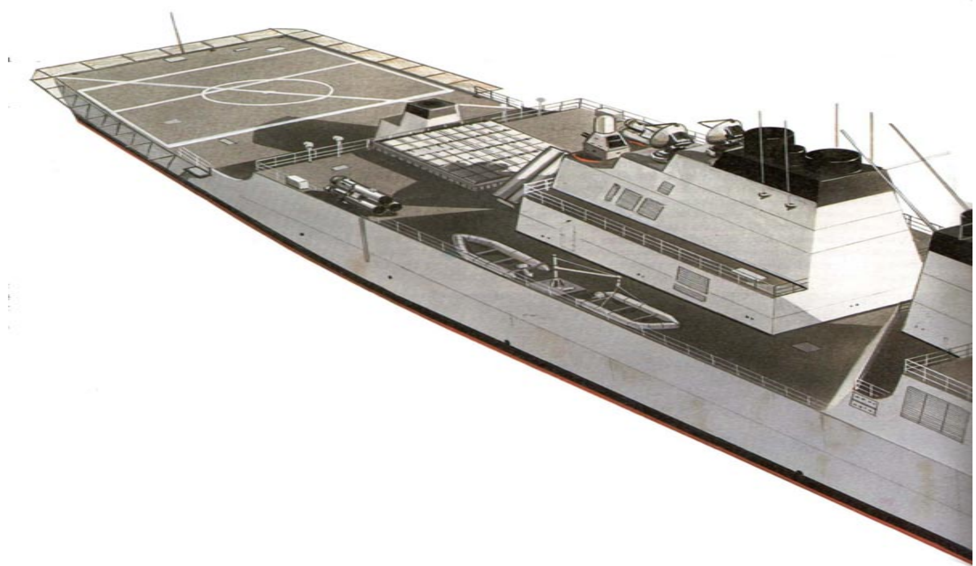

Figure 44: Helicopter Flight Deck

The construction of the helicopter hangar is the most visible change for this new generation of AEGIS Destroyers. Located aft of the after Vertical Launching System (VLS), the hangar is large enough to accommodate 2 SH-60F helicopters, support equipment, repair shops and store rooms. Modifications were also made for additional crew required for a helicopter detachment to deploy with the ship.

For the purposes of this analysis, the mission profile is for the AEGIS Destroyers to be able to accommodate one SH-60F helicopter and 1 MQ-8B Fire Scout.

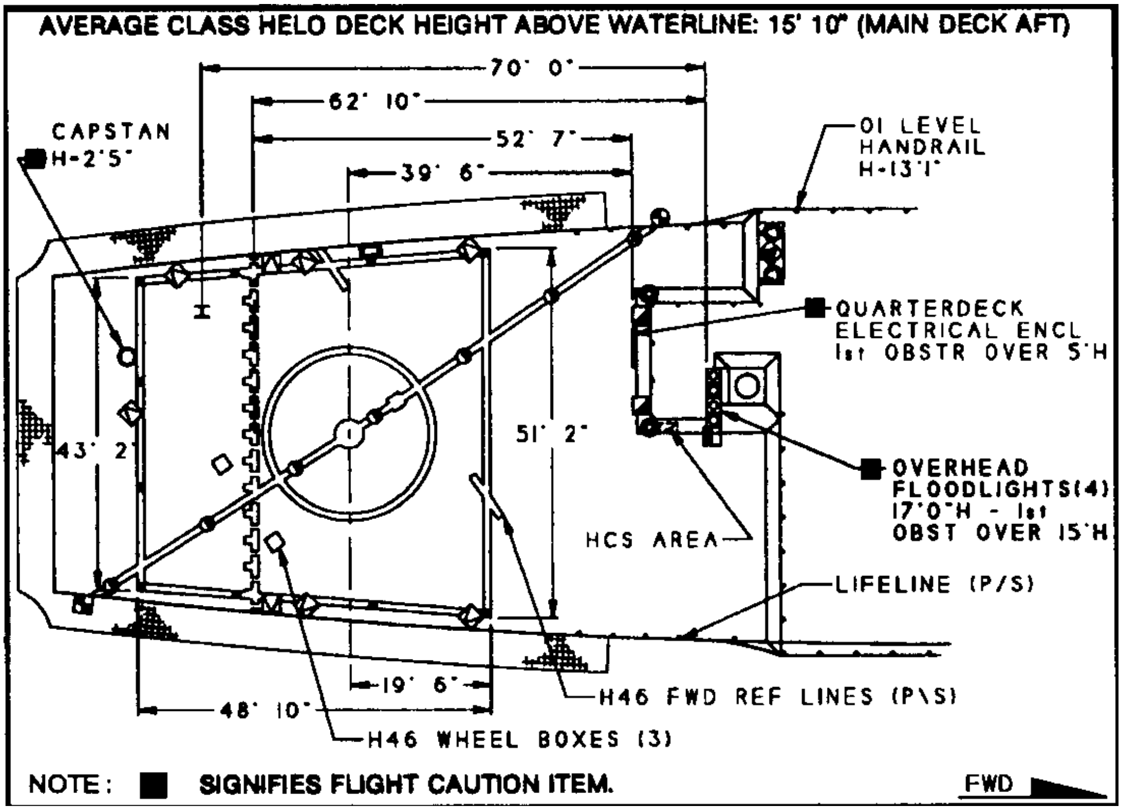

Figure 45: Detail Dimension of Helicopter Deck

4. Description of MQ-8B fire Scout

The MQ-8B Fire Scout is a Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle system that provides unprecedented situation awareness and precision targeting support for the future. The MQ-8B Fire Scout has the ability to autonomously take off and land on any aviation-capable warship and at prepared and unprepared landing zones in proximity to the soldier in contact.

Figure 46: MQ-8B Fire Scout

Figure 47: Fire Scout along side a Seahawk

Northrop Grumman has conducted several tests onboard U.S Navy ships with the Fire Scout and it has demonstrated stability in taking off and landing procedure.

Figure 48: Fire Scout landing on ship platform

IX. LOGISTICS

When operating in a logistically barren environment, there will be a need for a continuous flux of parts, equipment and fuel to support an operating force. Some items will be "pushed" into the operational theater on a regular basis, and will include items such as consumables and fuel. Other items will need to be "pulled", such as spare parts or fulfillment of unanticipated needs. This chapter begins by describing the statistical nature of parameters in a logistics system. Next, the results of modeling and simulation work describing the effectiveness of a force at conducting Maritime Interdiction Operations (MIO) are described as they related to unavailable assets. Finally, the two analyses were combined in a Monte-Carlo simulation to describe the degradation of an Expeditionary Strike Group (ESG) at conducting MIO in a logistically barren environment, e.g., as the uncertainty in arrival of materiel increases.

A. MEAN TIME BETWEEN FAILURES AND TIME TO SHIP

Poisson distributions can be thought of as the result of the intersection of a series of unfortunate (and unlikely) events. The rate at which necessary items needed to be repaired was assumed to be a Poisson distributed process. A Poisson process is a distribution useful for modeling non-negative integers with a single parameter. Poisson processes are normally associated with mean time between failures and are given by equation (9.1)

$$p(t;\lambda) = \frac{e^{-\lambda}\lambda^{t}}{t!} \tag{9.1}$$

Here, λ is the average mean time between failures for an arbitrary part, and time is the variable t. Figure 49 shows the approximate behavior for a Poisson distributed process as a response to average mean time between failures.

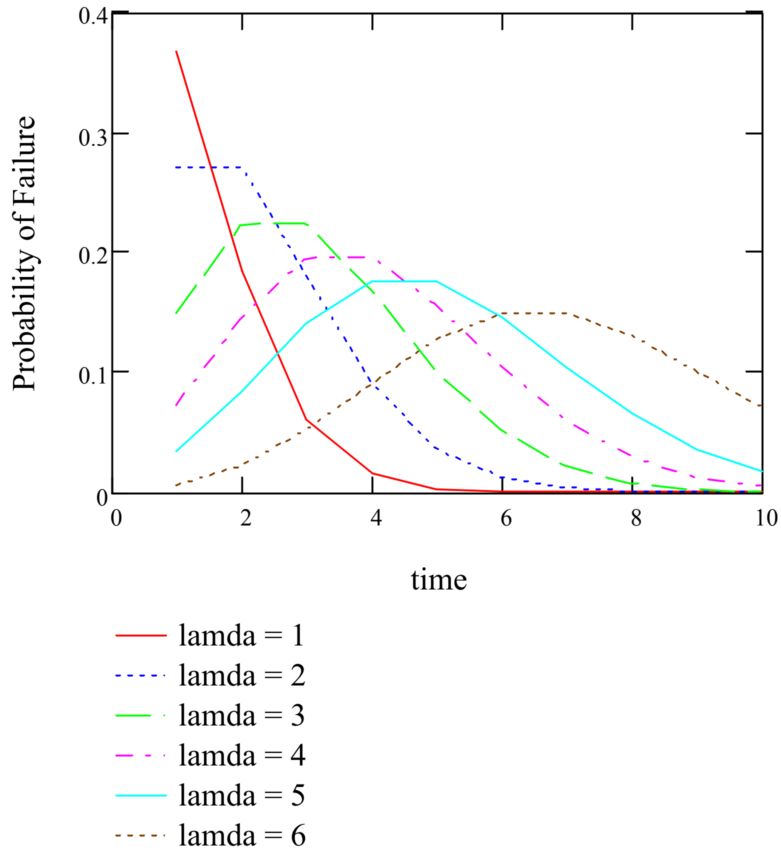

Figure 49: Probability of Failure of a Poisson Distributed Process

After a key component fails (such as an aircraft), it will be necessary to conduct a repair to be fully mission capable. For the purposes of this analysis, repairs that can be conducted in a period that is negligible in comparison to the amount of time it would take to have a replacement part shipped into a logistically barren environment were not considered. The amount of time taken to ship a replacement part into an operating theater was the primary variable of interest.

The amount of time taken to transport a part into an operating theater was assumed to be dependent on the geographic distance between the continental United States (CONUS) and the logistically barren environment where MIO forces are operating. Furthermore, consistent with the reasoning defined in chapter one discussing logistically barren environments, the time of arrival for a replacement item cannot be guaranteed.

Therefore, a statistical distribution was required to describe the amount of time to move a replacement part into theater.

The statistical distribution of in theater arrival times had several known key characteristics. For instance, there was a minimum amount of time for which to move a part into theater as a result of the relative speeds of aircraft and ships. This fact precludes the use of statistical distributions that are defined for negative values of time, such as the normal distribution. Furthermore, the employed statistical distribution must be exactly zero for the duration of time between when the replacement part was ordered and when the absolute minimum time that the part could arrive in theater.

One statistical distribution that has this characteristic is the log-normal distribution. Given by equation (9.2), the log-normal distribution was used to model the probability of a replacement part arriving in the logistically barren environment. The key variables were analyzed as a function of the average amount of time it takes to move a part into theater and the variance on that time. The values of μ and σ are parameters of the log-normal distribution but are not the expected value or variance of the distribution.

$$p(t;\mu,\sigma)=\frac{1}{t\sigma\sqrt{2\pi}}e^{-\frac{(\ln(t)-\mu)^2}{2\sigma^2}} \tag{9.2}$$

The expected value (E) and variance (V) of the statistical distribution are given by equations (9.3) and (9.4).

$$E(t)=e^{\mu+\sigma^2/2} \tag{9.3}$$

$$V(t)=e^{2\mu+\sigma^2}\bullet\left(e^{\sigma^2}-1\right) \tag{9.4}$$

Conversely, it can be shown that the parameters for a log-normal statistical distribution can be calculated given an anticipated expected value and variance. Equations (9.5) and (9.6) give these parameters for the log-normal statistical distribution as a function of a given expected value and variance.

$$\sigma(E,V)=\sqrt{\ln\left(\frac{V}{E^2}+1\right)} \tag{9.5}$$

$$\mu(E,V)=\ln(E)-\frac{1}{2}\ln\left(\frac{V}{E^2}+1\right) \tag{9.6}$$

The log-normal distribution is undefined below zero and requires a shift term to be introduced to indicate the absolute minimum amount of time for which a part could theoretically arrive in theater.

$$p(t;\mu,\sigma,\Delta t)=\frac{1}{(t-\Delta t)\sigma\sqrt{2\pi}}e^{-\frac{[\ln(t-\Delta t)-\mu]^2}{2\sigma^2}} \tag{9.7}$$

Equation (9.7) is a re-expression of equation (9.2) with a term added to shift the time by an amount Δt. To finish formulating the log-normal distribution as a model for shipment of replacement parts into a logistically barren environment, equation (9.7) is rewritten in terms of equations (9.5) and (9.6).

$$p(t;E,V,\Delta t)=\frac{1}{(t-\Delta t)\sigma(E,V)\sqrt{2\pi}}e^{-\frac{[\ln(t-\Delta t)-\mu(E,V)]^2}{2[\sigma(E,V)]^2}} \tag{9.8}$$

With these two processes defined as a function of the average time to transport a product into theater, the variance on that time, and the mean time between failures part of the framework was established for the creation of a Monte-Carlo simulation.

B. MODELING RESULTS

Chapter III of this report identified two basic scenarios that were explored in this analysis. The phase zero scenario was a basic problem of finding a single identifiable ship among a crowd of neutral shipping. Phase one was a series of MIOs done by an ESG where the number of ships to board vastly exceeded the boarding capacity of the ESG. Results from Chapter IV showed that in phase one, the number of operational aircraft was largely irrelevant to the success of the MIO task force. However, in phase zero, the availability of aircraft proved crucial to the success of the MIO mission.

Using the NSS scenario runs delimited in Chapter XI, a logistic regression analysis was completed on the Phase 0 analysis with critical factors Number of Aircraft sorties, a P-3 Long Range Surveillance craft in the area, and the type of short-range aircraft either SH-60 helicopters or VTUAVs. The graph below in Figure 50 shows the results based on the NSS runs. The P-3 in the scenario was treated as a categorical coded "0" if unavailable and "1" if available, since the P-3 relieves on station and is available for 24 hours. The Helo or UAV variable is also binary coded "0" for helo and "1" for UAV in the Equation in F.

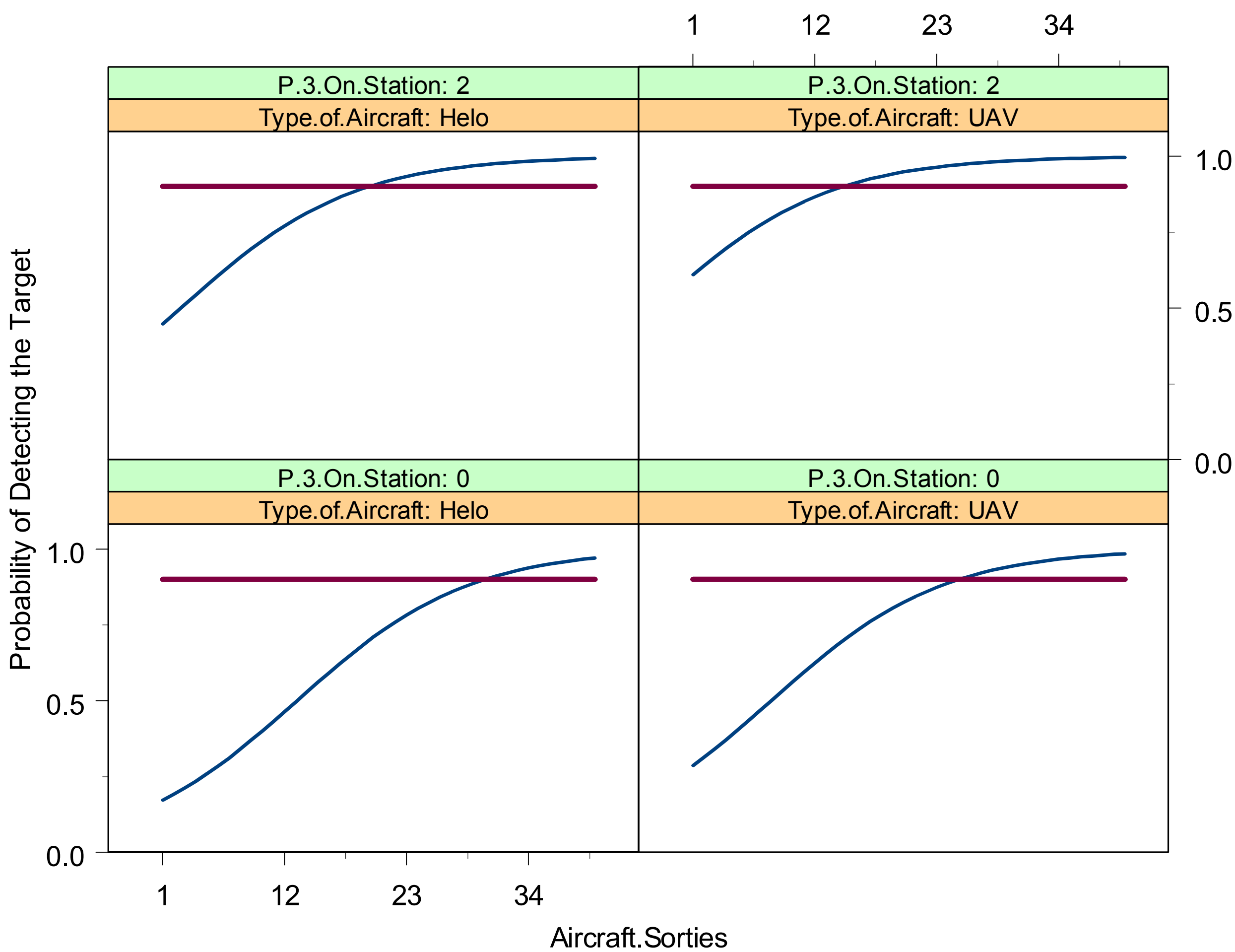

Figure 50: Logistic Regression Analysis for Phase 0 Aircraft

$$\ln\left(\frac{\pi_i}{1-\pi_i}\right) = -1.695 + 0.13 * x_{Aircraft.Sorties} + 1.35 * x_{P.3.OnStation} + 0.653 * x_{Aircraft.Type}$$

$x_{Aircraft.Sorties}$ is the Number of Aircraft Sorties from the Ships (9.9)

$x_{P.3.OnStation}$ is a Binary Variable for No P-3 or P-3 on Station (1)

$x_{Aircraft.Type}$ is a Binary Variable for Helo or UAV (1)

The graph and equation show that the P-3 and UAV require fewer sorties to find the single target. The Red Line in Figure 50 shows the 90% mission success intercept. The Logistic Regression equation above satisfies the Pearson Chi-Square Test for Significance of Regression and was based on 1064 NSS scenario runs. The simulation varied the number of aircraft sorties by prohibiting some aircraft from launching due to mechanical failures, which gives the data a degree of dispersion unlike the ship regression where the ships must be integer values in small range.

C. LOGISTICS IMPACTS ON PHASE ZERO OPERATIONS

The goal of the numeric logistics simulation shown in Figure 51 was to investigate the correlation between the effect that the parameters described in part A (E, V, and Δt) have on the probability of success of a MIO mission. This numeric logistics simulation is initialized by assuming a maximum number of operational aircraft available. For any given unit of time (e.g., day) in this simulation, the number of active aircraft generate a score for success of the MIO task force. The scoring was done in accordance with equation (9.9) and accumulated for every day of an operation over the course of a year.

Aircraft, in this simulation operated continuously for a period determined by the Poisson distributed random variable λ. Poisson distributed random numbers were used to simulate this mean time between failures. After an aircraft operated for the duration of the mean time between failures (and thereby accumulated success points for the MIO task force), the aircraft is non-mission capable. It will remain in a failed state (and therefore not accumulate any success points) for a log-normally distributed amount of time. The parameters of the log-normal distribution (E, V, and Δt) was used to generate random numbers with this distribution.

MathCad version 13 was used to develop this simulation. MathCad was the ideal choice of language as it allowed for the expression of complex mathematical algorithms with minimal amount of coding. The complete source for a single logistics simulation run is shown in Figure 51.

```
simulation(T, λ, E, V, Δt, N, scoring) := | score ← 0
                                          | break_times ← rpois(N, λ)
                                          | for i ∈ 0.. N − 1
                                          |   repair_times_i ← break_times_i + rlnorm(1, μ(E, V), σ(E, V))_0 + Δt
                                          | for t ∈ 0, 1.. T
                                          |   | n ← 0
                                          |   | for i ∈ 0.. N − 1
                                          |   |   | if (t > break_times_i) ∧ (t > repair_times_i)
                                          |   |   |   | break_times_i ← rpois(1, λ)_0 + t
                                          |   |   |   | repair_times_i ← break_times_i ...
                                          |   |   |   |          + rlnorm(1, μ(E, V), σ(E, V))_0 + Δt
                                          |   |   | n ← n + 1  if (t < break_times_i) ∧ (t < repair_times_i)
                                          |   | score ← score + scores_n·4
                                          | return score
```

Figure 51: MathCad Source Code for a Single Simulation run

In this simulation, the function 'rpois' generated random numbers with a Poisson distribution of λ. The function 'rlnorm' was used to generate log-normally distributed random variables with parameters of μ and σ. The resultant value returned by 'rlnorm' was then shifted by some amount, Δt, to compensate for the minimum amount of time necessary to transport a needed part into theater. The simulation program shown in Figure 51 was a time-step program and was not a discrete event as evidenced by the 'for' loop that runs from a starting value of t=0 up to t=T where t represents time, and T represents the entire length of time for the simulation to run. μ and σ were functions of E and V in this case, where E and V were the expected values of the distribution and variance, respectively. The functions for μ and σ were given by equations (9.5) and (9.6). N was the number of aircraft used in the simulation. Lower case 'n' represents the number of aircraft active at any instance of time. The array called "scores" is the values of equation (9.9). The value retrieved from this array is multiplied by four in order to account for the assumption that each operational aircraft can generate four sorties per day. The total score for each run is then divided by 365 in order to generate an average probability of success over a year for a given MIO campaign.

Due to the research nature of this analysis, the source code of Figure 51 was parameterized by all the key performance parameters of a logistics system. The last passed parameter was a function called “scoring”. This function is passed as a parameter. For the purposes of this discussion, the scoring function is shown in equation (9.9).

As stated at the beginning of this chapter, this simulation showed the effectiveness of a MIO task force as a function of the key performance parameters of a logistic system. The program detailed in Figure 51 was the core of this simulation. In order to determine the value (in terms of cumulative daily effectiveness) of the MIO task force, the program of Figure 51 was run for one-thousand iterations at each selected value of input parameters.

To evaluate equation, all variables were set to arbitrary but fixed values. The mean time between failures (λ) was set to ten days. The expected value (E) of the log-normal distribution was set to fifteen days. The variance was set to two days. The minimum time to receive a replacement part in the logistically barren environment (Δt) was assumed to be ten days, with no variability in time. Four helicopters were assumed (N=4) and 365 days was assumed to be the length of time for which to run this simulation.

In order to see the effect on the MIO task force’s ability to do phase zero operations, simulations were run for values of Δt ranging from ten to one-hundred in increments of ten days. As is shown in Figure 52, there is a sharp degradation of performance as the operating environment becomes increasingly barren.

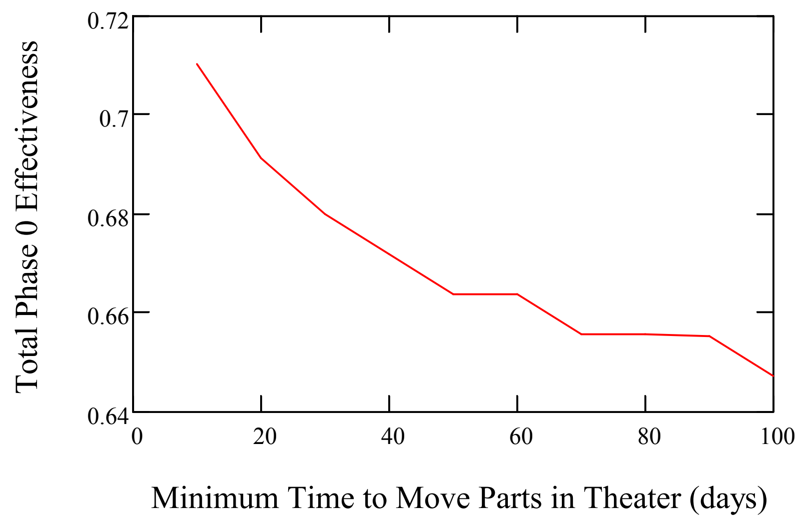

Figure 52: MIO Effectiveness as Re-supply Distance Increases

By only increasing the minimum amount of time to transport a part into theater, the supply line is assumed to be the same, but just longer. This assumption neglects the fact that with each logistics node (airport, seaport, warehouse, etc), the probability for a delay inducing error increases. In order to compensate for this, both the expected value and variance of the log-normal distribution are increased equally with increasing Δt. This added condition models a lengthening and increasingly imperfect supply line. A base expected value of ten days was used and increased by the same amount that Δt is increased. The initial variances started at two days, and were increased by the same amount for each iteration.

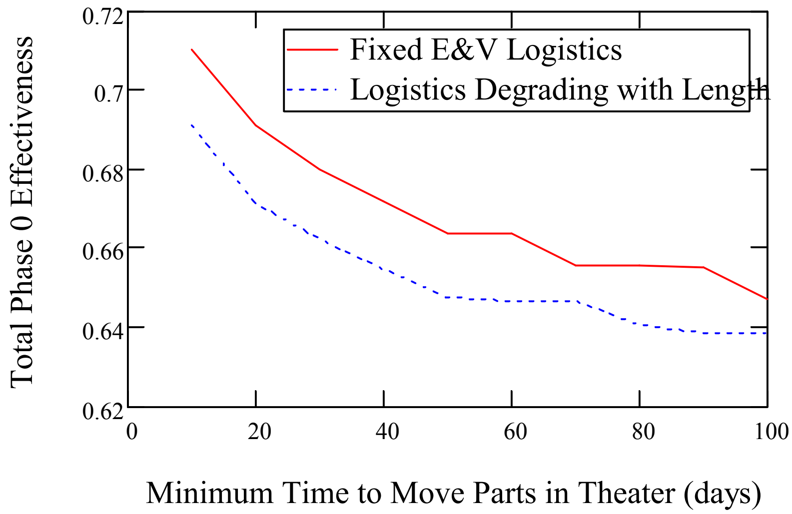

Figure 53: MIO Effectiveness as Distance from Re-supply Increases

Lastly, the mean time between failures (λ) is increased while E, V and Δt are held constant at ten, two and ten days, respectively. Here, λ was increased by factors of ten as in previous runs.

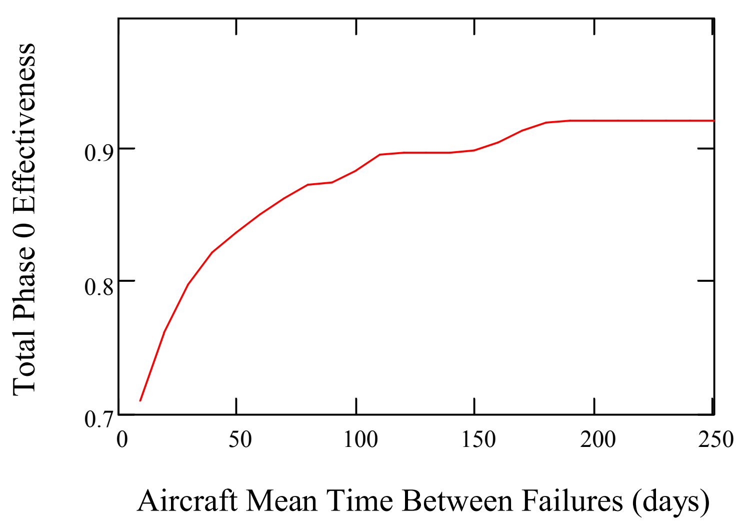

Figure 54: MIO Effectiveness as a Function of λ

D. CONCLUSIONS

Increasing the mean time between failures has a diminishing effect as the time it takes for an aircraft to fail approaches that of the duration of the MIO mission. For small values of aircraft mean time between failures, a small improvement in aircraft availability increases the overall effectiveness by a disproportionally greater amount of time.

For a “pull” type logistics system where major aircraft repairs require parts to be shipped into the logistically barren environment, the degradation of a MIO mission will occur most significantly if the required part is not moved into theater in a relatively small amount of time. If the required part fails to make it into the required theater early in the process, the degradation to the mission is statistically non-linear and less affected. As a result, anticipating equipment failures, conducting preventative maintenance and shipping parts into theater before they are needed (as would be the case with high failure rate items) will produce a positive effect on mission readiness.

Overall, a small improvement in the mean time between failures has a greater effect on the phase zero mission performance than does an improvement in the logistics pipeline. In short, the analysis shown here shows that it is statistically preferred to have a few well maintained aircraft that have a lengthy mean time between failures than it is to have aircraft that break frequently but can get replacement parts easily. Fiscal resources are better spent making more reliable aircraft than they are in improving the supporting logistics.

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X. COST ESTIMATION

A. METHODOLOGY

Cost Estimation is essentially the process whereby the collection and analysis of historical data is accomplished by one of four methodologies: parametric, analogy, engineering build-up, or quantitative models (techniques, tools and databases) to predict the future cost of an item, product, program, or task. All cost estimates are normalized (inflation-adjusted) on information to 2008 dollars. This chapter outlines the cost estimates that were made to support MIO during the first thirty days of operations. In some instances, these costs included the acquisition of MIO specific materiel that was amortized over the lifecycle of the equipment. Additionally, by using assumptions based on usage rates and expert opinion (i.e., the methodology of analogy) regarding operations and support (O & S) costs, the second thirty-day cost estimate was estimated.

The purpose of cost estimation was to allow the translation of system and functional requirements associated with programs, projects and MIO processes into budgetary requirements.

Numerous types of data were used for cost estimation, including (1) historical costs, and labor costs for cost data; (2) performance metrics, physical characteristics, technology descriptors, and operational environment for technical and operational data; and (3) production quantities and rates, design changes, and quantities produced for manufacturing data. The two primary sources of data for the cost estimates were from open sources and interviews of ‘experts’[61].

61 The mode of seeking advice from Subject Matter Experts (SMEs) has been used in some of the cost estimation.

1. Approach to Cost Estimation

The seven-step approach taken for the project's cost estimation was as follows:

(i) Logistics requirements were gathered from the respective functional areas associated with Maritime Interdiction Operations (MIO).

(ii) Estimation of the quantity required was then taken from underlying assumptions, experiential inputs, open source data, and the generated CONOPS.

(iii) The functional requirements of a MIO were converted to a MIO work breakdown structure (WBS) to capture WBS level-two cost estimates that covered Operations, Maneuver, Search, Boarding and Communications.

(iv) Unit costs were determined to be in or out of scope; with in-scope estimates subsequently assigned to each of the functional logistics requirements.

(v) Cost estimating methodologies were selected to consider the lifecycle phases of a MIO and materiel as well as the availability of source data. Of the four cost estimating methodologies, primary emphasis was placed on engineering build-up, supplemented to a lesser extent by analogy, parametric, and modeling.

(vi) Data were gathered and normalized by adjusting for inflation to the baseline year of constant FY08 dollars.

(vii) Point estimates were then developed and reported in this chapter.

2. Assumptions

The following assumptions were made to obtain cost estimates that were both realistic and applicable to the study of MIO in a logistically barren environment:

(i) Duration of Estimates. In order to amortize the costs of materiel over a sizeable overall quantity, it was assumed there would be (1) fifty MIOs within as given period of thirty days of operation and (2) lifecycle issues were described in terms of multiple years. The cost estimates were then taken over the first thirty days of operation.

(ii) Recurrent Versus Non-Recurrent Cost. Recurrent Costs during the Operations and Support (O & S) phase for most equipment was assumed to be greater than the initial procurement cost (Non-Recurrent), since the O & S phase lasts until the equipment is disposed. The open source data for these operating costs reflected commercial best pricing and not the Navy-burdened real costs. In a few instances, reliance on expert opinion provided the basis for estimating costs of some disposable items (e.g., latex gloves, etc.).

Due to the elaborately complex nature of determining the cost of a vessel (which is essentially a 'sunk' cost given the project timeframe of 2013-2014), only the operation and support costs for vessels and unit level maintenance costs were considered.

(iii) Fiscal Year Tabulation. Cost estimates were calculated in the fiscal year of 2008 (FY08$).

B. ESTIMATION FOR OPERATIONS MANAGEMENT

1. Operations - Ships

All cost information for operating ships was taken from Excel data sheets provided by the Navy Visibility and Management of Operating and Support Costs (VAMOSC) management information system. The MIO function 'Maneuver' included the components that comprise the Expeditionary Strike Group (ESG). As outlined in the Concept of Operations, the ESG was comprised of the following U.S. Navy assets: (1) LHD; (1) LPD; (1) LSD; and (1) CG. The number of DDG(s) varied depending on the phase of operations. Cost estimates for the

P-3C and SH-60B were also included in this section. The number of aircraft was dependent on the phase of operation.

Cost estimates for the LHD were based on the WASP (LHD 1) class ship; beginning with the WASP (LHD 1) and ending with IWO JIMA (LHD 7). These estimates consisted of costs attributed in FY07 based on entries by hull number. For each hull the total operating cost was calculated by summing the Direct Unit Cost and the Intermediate Maintenance Cost. Direct Unit Cost consisted of the following sub-categories: Personnel, Unit Level Consumption, and Purchased Services. Intermediate Maintenance Costs were comprised of Intermediate Maintenance - Labor, Intermediate Maintenance - Material, and Commercial Industrial Services/Indefinite Delivery, Indefinite Quantify Contracts. Not included were costs associated with Maintenance and Modernization.

The estimated total operating cost for each LHD was calculated using the following equation:

Direct Unit Cost + Intermediate Maintenance Cost = Total Operating Cost (FY07)

The average operating cost was then calculated using the equation:

$$\frac{\text{Total Operating Cost (Annual)}}{\text{Total Number of Ships}} = \text{Annual Average Cost per ship}$$

$$\text{Average Cost for First Thirty Days of Operations} = \text{Annual Average Cost per ship} * \frac{\text{30 days}}{\text{365 days}}$$

Dividing the Average Cost per ship by 365, gives the average operating cost per day; finally, in order to calculate the cost to operate (1) LHD per thirty-days, the Average Cost per ship was multiplied by 30.

Cost estimates for the LPD were based on the SAN ANTONIO (LPD 17) class ship; beginning with the SAN ANTONIO (LPD 17) and ending with NEW ORLEANS (LPD 18). Estimates were based only on these ships for the following two reasons: Firstly, each of the currently employed Austin Class LPD(s) (LPD 7 through LPD 15) are expected to be decommissioned no later than 2015, which is approximately the timeframe of this project's execution. Secondly, year 2007 operating cost information was available for only the two newest SAN ANTONIO Class LPD(s), hull numbers17 and 18.

Identical to the procedure used previously to estimate the cost information for the LHD, data for the LPD was also extracted from the VAMOSC data sheets and used to calculate the total operating costs, average cost per ship, and ultimately the cost to operate one LPD for thirty-days.

Cost estimates for the LSD were an average based on the WHIDBEY ISLAND (LSD 41) class ship and the HARPERS FERRY (LSD 49) class ship. The same procedures and equations were used to calculate the cost to operate one LSD for thirty-days.

Similarly, data for the TICONDEROGA Class (CG 47) was also taken from the VAMOSC data sheets. Beginning with Baseline two ships, estimates included hull numbers 52 through 73. The cost to operate one CG for thirty-days was also calculated.

Data for the DDG 51 Class (Flt IIA) was taken from the VAMOSC data sheets outlining O&S cost and counts, and consisted of costs associated with year 2007 operating costs based on hull numbers 79 through 101. The same equations were used to calculate the total operating costs, average cost per ship, and ultimately the cost to operate one DDG (Flt IIA) for thirty-days.

2. Operations – Aircraft

As outlined in the Concept of Operations, the P-3C and the SH-60B were elements of the Maritime Interdiction Operation. Cost estimates for the P-3C were based on the data taken from VAMOSC. For each aircraft, the total operating cost was calculated by summing the Mission Personnel, Unit Level Consumption, Intermediate Maintenance, Contractor Support, Sustaining Support and Indirect Support. Not included were costs associated with Depot Maintenance.

The total estimated operating cost for (33) P-3C during FY07 was calculated using the following equation:

Mission Personnel + Unit Level Consumption + Intermediate Maintenance + Contractor Support + Sustaining Support + Indirect Support = Total Operating Cost

Using the above total operating cost per 154 aircraft[62], the operating cost per aircraft was then calculated using the equation:

$$\frac{TotalOperatingCost}{154} = Cost \text{ Per P-3C per year}$$

Dividing the Average Cost per aircraft by 365, yields the average operating cost per day; multiplying the operating cost per day by 30 calculates the cost to operate (1) P-3C per thirty-days. From this calculation, the cost to operate one squadron of P-3C aircraft was estimated and shown in Table 1.

Using the same data source, procedure and equations, cost estimates were calculated for the SH-60B (145 aircraft were used in the denominator).

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62 VAMOSC Data Sheet (Aviation)

C. ESTIMATES

The estimates presented in the following tables outlined the cost estimates for each of the functional areas of MIO. Estimates were also made for the operations of two, six and ten ships for the first 30 days and the subsequent 30 days. The estimated cost for each MIO totaled USD$22,000 per, for a two-ship operation. The top three cost drivers for each of the periods were also analyzed, as depicted in Figure 55. The relative cost estimates for the two periods (first 30 days and next 30 days) with the employment of two, six and ten ships is depicted in Figure 56.

Top Three Contributors for 2 Ships		
Cost Drivers Priority	**First 30 Days**	**Second 30 Days**
1	Maneuver	Ship O&S
2	Ship O&S	Maneuver
3	Boarding	Search

Top Three Contributors for 6 Ships		
Cost Drivers Priority	First 30 Days	Second 30 Days
1	Maneuver	Ship O&S
2	Ship O&S	Maneuver
3	Boarding	Search

Top Three Contributors for 10 Ships		
Cost Drivers Priority	First 30 Days	Second 30 Days
1	Ship O&S	Ship O&S
2	Maneuver	Maneuver
3	Boarding	Search

Figure 55: Cost Drivers in Each Period

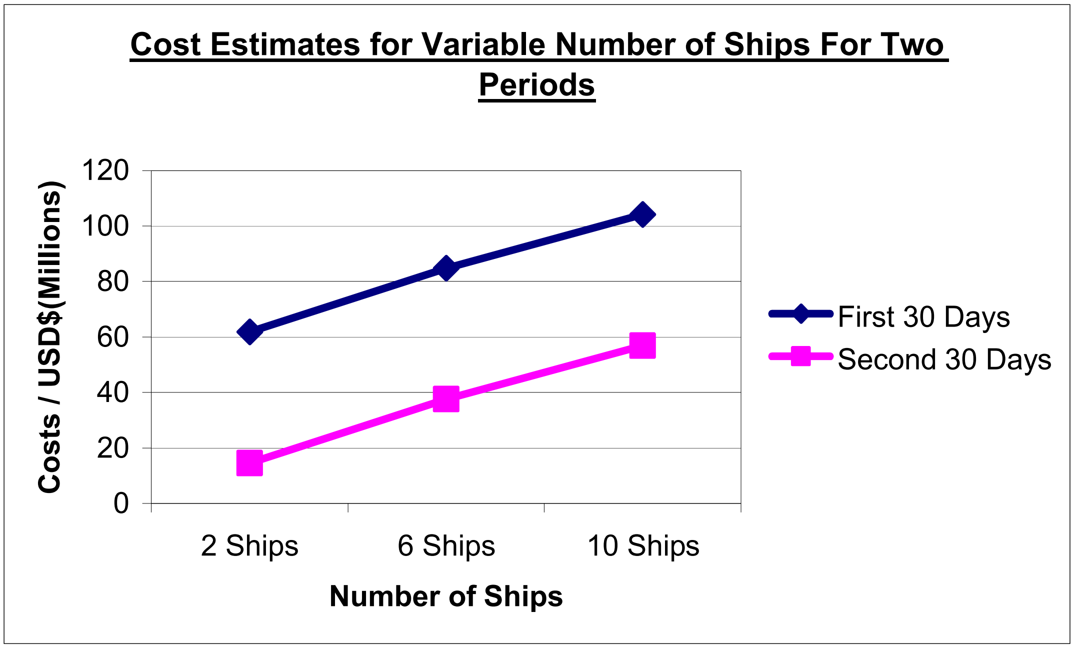

Figure 56: Cost Estimates for Variable Number of Ships for Two Periods

	Assumptions	Qty Required	Unit Cost/per year	Cost for First 30 days	Total Cost for First 30 days	Reference
LHD		1	$ 105,576,756	$ 8,677,542	$ 8,677,542	VAMOSC Data Sheet (Ships) www.navyvamosc.com
LPD		1	$ 28,333,792	$ 2,368,365	$ 2,368,365	VAMOSC Data Sheet (Ships) www.navyvamosc.com
LSD		1	$ 33,312,830	$ 2,738,041	$ 2,738,041	VAMOSC Data Sheet (Ships) www.navyvamosc.com
CG		1	$ 43,772,167	$ 3,597,712	$ 3,597,712	VAMOSC Data Sheet (Ships) www.navyvamosc.com
DDG Flt IIA		2	$ 34,340,580	$ 2,822,513	$ 5,645,026	VAMOSC Data Sheet (Ships) www.navyvamosc.com
SH-60B	One det consists of 2 aircraft	6	$ 3,839,498	$ 315,575	$ 1,893,451	VAMOSC Data Sheet (Aviation) www.navyvamosc.com
P-3C	One squadron is comprised of 9 aircraft	9	$ 8,026,334	$ 659,698	$ 5,937,288	VAMOSC Data Sheet (Aviation) www.navyvamosc.com
Total for FIRST 30 days (USD$) (FY08$) 6 Ship ESG					$30,857,425	

Table 30: Cost Estimates for Operations

LHD

Hull Number	Constant FY 08 Dollars Total Operating Cost
1	$ 97,330,074
2	$ 113,151,037
3	$ 104,613,129
4	$ 116,376,702
5	$ 106,941,747
6	$ 113,777,530
7	$ 86,847,071

Direct Unit Cost	Intermediate Maintenance	Other Operating & Support	Total Operating Cost (each Ship)
$ 93,182,249	$ 765,547	$ 3,382,278	$ 97,330,074
$ 106,636,185	$ 2,871,260	$ 3,643,593	$ 113,151,037
$ 99,301,249	$ 1,918,578	$ 3,393,302	$ 104,613,129
$ 112,122,433	$ 717,976	$ 3,536,293	$ 116,376,702
$ 103,259,579	$ 214,810	$ 3,467,358	$ 106,941,747
$ 109,854,040	$ 255,643	$ 3,667,847	$ 113,777,530
$ 81,287,748	$ 2,354,222	$ 3,205,101	$ 86,847,071

Total # of Ships	7	$ 105,576,756	average cost per 365 days	$\frac{TotalOperatingCost(eachShip)}{7} =$ Average cost per year for 1 Ship
		$ 289,251	per day	Average Cost per year 1 Ship / 365 days
		$ 8,677,542	**per 30 days**	Cost per day * 30 days

Table 31: 30 Day Operating Cost for LHD

LPD

Hull Number	Constant FY 08 Dollars Total Operating Cost
17	$ 29,333,792
18	$ 28,296,421

Direct Unit Cost	Intermediate Maintenance	Other Operating & Support	Total Operating Cost (each Ship)
$ 27,306,844	$ 840,786	$ 1,186,161	$ 29,333,792
$ 27,038,398	$ 75,836	$ 1,182,188	$ 28,296,421

Total # of Ships **2**

$ 28,815,106	average cost per 365 days	$\frac{TotalOperatingCost(eachShip)}{2} =$ Average cost per year for 1 Ship
$ 78,945	per day	Average Cost for 1 ship per year / 365 days
$ 2,368,365	**per 30 days**	Cost per day * 30 days

Table 32: 30 Day Operating Cost for LPD

LSD

Hull Number	Constant FY 08 Dollars Total Operating Cost	Direct Unit Cost	Intermediate Maintenance	Other Operating & Support	Total Operating Cost (each Ship)
49	$ 34,234,783.61	$ 30,299,954	$ 2,896,343	$ 1,038,487	$ 34,234,784
50	$ 32,680,871.92	$ 31,097,710	$ 601,559	$ 981,603	$ 32,680,872
51	$ 35,583,459.50	$ 30,399,596	$ 4,187,626	$ 996,237	$ 35,583,459
52	$ 30,752,205.28	$ 29,088,272	$ 546,390	$ 1,117,543	$ 30,752,205

Total # of Ships	**4**		
	$ 33,312,830	Average cost per 365 days	$\frac{TotalOperatingCost(eachShip)}{4} =$ Average cost per year for 1 Ship
	$ 91,268	per day	Average Cost for 1 ship per year / 365 days
	$ 2,738,041	**per 30 days**	Cost per day * 30 days

Table 33: 30 Day Operating Cost for LSD

CG

Hull Number	Constant FY 08 Dollars Total Operating Cost	Direct Unit Cost	Intermediate Maintenance	Other Operating & Support	Total Operating Cost (each Ship)
52	$ 45,589,681	$ 43,313,684	$ 921,735	$ 1,354,261	$ 45,589,681
53	$ 36,383,732	$ 33,931,209	$ 846,091	$ 1,606,433	$ 36,383,732
54	$ 52,153,025	$ 49,969,211	$ 897,856	$ 1,285,958	$ 52,153,025
55	$ 31,887,859	$ 29,712,187	$ 1,050,695	$ 1,124,977	$ 31,887,859
56	$ 35,617,106	$ 33,828,371	$ 682,233	$ 1,106,502	$ 35,617,106
57	$ 42,641,764	$ 40,103,972	$ 1,007,999	$ 1,529,793	$ 42,641,764
58	$ 37,856,737	$ 33,719,220	$ 2,960,097	$ 1,177,420	$ 37,856,737
59	$ 53,280,622	$ 50,352,155	$ 1,473,336	$ 1,455,131	$ 53,280,622
60	$ 55,580,840	$ 38,217,390	$ 16,322,452	$ 1,040,998	$ 55,580,840
61	$ 41,033,282	$ 39,122,519	$ 892,906	$ 1,017,857	$ 41,033,282
62	$ 34,519,968	$ 31,287,502	$ 1,367,653	$ 1,864,812	$ 34,519,968
63	$ 49,330,446	$ 46,233,068	$ 2,001,334	$ 1,096,045	$ 49,330,446
64	$ 40,055,115	$ 37,125,850	$ 1,850,997	$ 1,078,268	$ 40,055,115
65	$ 50,045,147	$ 48,661,933	$ 313,189	$ 1,070,025	$ 50,045,147
66	$ 36,653,537	$ 34,524,343	$ 1,034,160	$ 1,095,033	$ 36,653,537
67	$ 48,515,942	$ 40,315,085	$ 7,141,695	$ 1,059,162	$ 48,515,942
68	$ 50,629,654	$ 44,708,676	$ 4,836,038	$ 1,084,940	$ 50,629,654
69	$ 39,489,761	$ 37,505,822	$ 931,512	$ 1,052,428	$ 39,489,761
70	$ 68,232,245	$ 66,615,446	$ 514,695	$ 1,102,104	$ 68,232,245
71	$ 29,309,112	$ 27,076,500	$ 969,463	$ 1,263,149	$ 29,309,112
72	$ 42,906,527	$ 41,546,489	$ 296,728	$ 1,063,310	$ 42,906,527
73	$ 41,275,572	$ 38,916,617	$ 1,141,958	$ 1,216,997	$ 41,275,572

Total # of Ships **22**

$ 43,772,167	Average cost per 365 days	$\frac{TotalOperatingCost(eachShip)}{22} =$ Average cost per year for 1 Ship
$ 119,924	per day	Average Cost for 1 ship per year / 365 days
$ 3,597,712	**per 30 days**	Cost per day * 30 days

Table 34: 30 Day Operating Cost for CG

DDG Flt IIA

Hull Number	Constant FY 08 Dollars Total Operating Cost	Direct Unit Cost	Intermediate Maintenance	Other Operating & Support	Total Operating Cost (each Ship)
79	$ 29,930,858	$ 28,285,416	$ 757,076	$ 888,365	$ 29,930,858
80	$ 37,933,995	$ 35,227,859	$ 1,793,667	$ 912,469	$ 37,933,995
81	$ 30,801,266	$ 29,042,820	$ 836,292	$ 922,154	$ 30,801,266
82	$ 39,909,128	$ 35,915,218	$ 3,046,219	$ 947,691	$ 39,909,128
83	$ 40,508,925	$ 38,453,407	$ 621,168	$ 1,434,350	$ 40,508,925
84	$ 31,201,652	$ 29,447,303	$ 778,982	$ 975,367	$ 31,201,652
85	$ 33,473,390	$ 31,892,291	$ 459,392	$ 1,121,707	$ 33,473,390
86	$ 30,253,849	$ 28,417,650	$ 779,138	$ 1,057,060	$ 30,253,849
87	$ 36,272,467	$ 34,801,797	$ 514,149	$ 956,522	$ 36,272,467
88	$ 42,744,983	$ 41,262,881	$ 379,352	$ 1,102,751	$ 42,744,983
89	$ 38,817,679	$ 36,346,163	$ 1,532,875	$ 938,641	$ 38,817,679
90	$ 46,158,888	$ 44,893,382	$ 365,303	$ 900,202	$ 46,158,888
91	$ 39,567,401	$ 38,331,709	$ 277,619	$ 958,073	$ 39,567,401
92	$ 28,954,345	$ 26,678,588	$ 1,232,401	$ 1,043,356	$ 28,954,345
93	$ 44,828,738	$ 43,681,512	$ 226,952	$ 920,274	$ 44,828,738
94	$ 35,784,920	$ 34,704,809	$ 179,391	$ 900,720	$ 35,784,920
95	$ 34,087,495	$ 32,616,834	$ 567,696	$ 902,965	$ 34,087,495
96	$ 34,212,755	$ 32,919,278	$ 389,811	$ 903,666	$ 34,212,755
97	$ 33,336,285	$ 31,783,023	$ 396,990	$ 1,156,272	$ 33,336,285
98	$ 32,140,327	$ 30,992,669	$ 211,174	$ 936,484	$ 32,140,327
99	$ 19,940,879	$ 18,961,457	$ 90,663	$ 888,758	$ 19,940,879
100	$ 23,890,569	$ 22,886,405	$ 221	$ 1,003,944	$ 23,890,569
101	$ 25,082,544	$ 24,188,219	$ 37,488	$ 856,837	$ 25,082,544

Total # of Ships **23**

$ 34,340,580	Average cost per 365 days	$\frac{TotalOperatingCost(eachShip)}{23} =$	Average cost per year for 1 Ship
$ 94,084	per day	Average Cost for 1 ship per year / 365 day	
$ 2,822,513	**per 30 days**	Cost per day * 30 days	

Table 35: 30 Day Operating Cost for DDG

P-3C

Constant FY 08 Dollars

Mission Personnel	Unit Level Consumption	Intermediate Maintenance	Contractor Support	Sustaining Support	Indirect Support	Total Operating Cost
$ 428,339,561	$ 450,667,895	$ 85,289,866	$ 3,665,278	$ 253,383,308	$ 14,709,634	$ 1,236,055,542

Total Aircraft	154	$	1,236,055,542.00	Cost per year for **154** aircraft	
		$	8,026,334.69	Cost per year for **1** aircraft	$\frac{TotalOperatingCost(per154A/C)}{154} =$ cost per year for 1 A/C
		$	8,026,334.69	per 365 days	
		$	21,989.96	per day	Cost per year for 1 Aircraft / 365 days
		$	**659,698.74**	**per 30 days**	Cost per day * 30 days

SH-60B

Constant FY 08 Dollars

Mission Personnel	Unit Level Consumption	Intermediate Maintenance	Contractor Support	Sustaining Support	Indirect Support	Total Operating Cost
$ 239,940,779	$ 233,685,652	$ 44,558,994	$ 5,569,252	$ 28,948,709	$ 4,023,847	$ 556,727,233

Total Aircraft	145	$	556,727,233.00	Cost per year for **145** aircraft	
		$	3,839,498.16	Cost per year for **1** aircraft	$\frac{TotalOperatingCost(per145A/C)}{145} =$ cost per year for 1 A/C
		$	3,839,498.16	per 365 days	
		$	10,519.17	per day	Cost per year for 1 Aircraft / 365 days
		$	**315,575.19**	**per 30 days**	Cost per day * 30 days

Table 36: Aircraft Costs per 30 Days

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$ (in millions)	Total Cost FIRST 30 days / USD$ (in millions)	Reference	Assumptions	Next 30 days operation cost (M USD$)
Maneuver										
UAV	Platform	Piece	1 Platform per Destroyer	One time cost at purchase for Equipment	2	15	30	www.deagel.com/Tactical-Unmanned-Rotorcrafts	5% of Acq Cost for Annual O&S oost	0.125
USV	Platform	Piece	2 Platform per Destroyer	One time cost at purchase for Equipment	4	4	16	www.defenseindustrydaily.com/	5% of Acq Cost for Annual O&S oost	0.067
Hellfire	Munition	Piece	1 per engagement	50 boardings per 30 days of operations (assume 20% hostile).	10	0.068	0.68	en.wikipedia.org	Reorder	0.680
Chain Gun (M230)	Accessories	Piece	1 per platform	One time cost at purchase for Equipment	2	0.1	0.2	www.ausa.org/webpub	Ammunition, some planned maintenance	0.100
LRAD	Accessories	Piece	1 per platform	One time cost at purchase for Equipment	4	0.030	0.12	www.signonsandiego.com/uniontrib/20051109	Maintenance (Mx)	0.010
Total for FIRST 30 days (USD$) (FY$08 in Millions)							**$47**	Total for NEXT 30 days (USD$) (FY$08 in Millions)		**$0.982**

Table 37: Cost Estimates for Maneuver

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumptions	Next 30 days cost
Search										
Sabre 4000	Search Equipment	Piece	3 Equipment per Mission	One time cost at purchase for Equipment	3	25,466	76,398	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Mx	1,000
Swabs	Search Equipment - Accessories	Piece	200 Pieces per Boarding	50 Boardings per 30 days	10,000	0.40	4,000	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	reorder	4,000
Spare Batteries	Search Equipment - Accessories	Pack	5 Pack of Battery for 50 boardings per 30 days of operations	Each Pack of Battery last for 100 hours of operation, Each Operation will last for 10 hours, hence each Pack of Battery good for 10 operations ~ 5 Pack of Battery for 50 boardings per 30 days of operations. Assume 8 sets	40	1,327	53,080	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	53,080
Air purification cartridges	Search Equipment - Accessories	Pack	1 cartridge for 30 days of operatio	1 cartridge for 30 days of operations	3	66.67	200	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	200

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumptions	Next 30 days cost
Search										
			ns							
Membranes	Search Equipment - Accessories	Pack	1 cartridge for 30 days of operations	1 cartridge for 30 days of operations	3	29	87	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	87
Vapor Card	Search Equipment - Accessories	Pack	1 Piece per equipment per operation	2 equipment used per operation	100	13.40	1,340	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	1,340
Vesitics - Explosive Mode	Search Equipment - Accessories	Piece	1 piece per equipment per mode for 30 days of operations	1 piece per equipment per 30 days of operation	3	167	501	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	501
Vesitics - Narcotics Mode	Search Equipment - Accessories	Piece	1 piece per equipment per mode for 30 days of	1 piece per equipment per 30 days of operation	3	167	501	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	501

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumptions	Next 30 days cost
Search										
			operations							
Vesitics - Chemical Mode	Search Equipment - Accessories	Piece	1 piece per equipment per mode for 30 days of operations	1 piece per equipment per 30 days of operation	3	100	300	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Reorder	300
Gloves	Search Equipment - Accessories	Pair	30 Pairs per Boarding	50 Boardings per 30 days	1,500	0.15	225	http://www.ares-server.com/Ares/Ares.asp?MerchantID=RET01229&Action=Catalog&Type=Product&ID=81781	Reorder	225
Interactive Training CD-ROM	Search Equipment - Accessories	Number	1 CD	One time cost at purchase for Equipment	1	1,842	1,842	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Nil	0
Onsite Training Class	Search Equipment - Accessories	Number	1 Course per Operator	One time cost at purchase for Equipment, train 4 operators at on start, then	4	1,600	6,400	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Train	200

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumptions	Next 30 days cost
Search										
				conduct internal training for subsequent operators						
Dogs	Search Equipment	Animal	3 Dogs per Mission	One time cost at purchase for Dogs	3	10,000	30,000	http://www.cqbk9.com/payments.html	Nil	0
Vetenarian	Dog Accessories	Man	1 Man per 10 Dogs	Tied to the pay scale of a Lieutenant (O3) between 8-10 years of service	1	5,000	5,000	http://www.military.com/military/benefits/0,15465,2008-military-pay-charts,00.html	Nil	5,000
Dog Handling Course	Dog Accessories	Number	1 Course per Dog	One time cost at purchase for Dogs	3	5,500	16,500	http://www.cqbk9.com/payments.html	Nil	0
Harness	Dog Accessories	Piece	2 Pieces per Dog	NIL	6	90	540	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Nil	0
Search Vest	Dog Accessories	Piece	2 Pieces per Dog	NIL	6	50	300	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Nil	0
Leash / Collars	Dog Accessories	Piece	2 Pieces per Dog	NIL	6	30	150	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Nil	0
K9 First Aid Kit	Dog Accessories	Set	1 set per 2 Dogs	NIL	5	50	250	http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219660a.pdf	Restock	100

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumptions	Next 30 days cost
Search										
Shampoo / Soap	Dog Accessories	Set	3 set per Dog per 2 weeks	NIL	18	70	1,260	http://www.medi-vet.com/dogs.aspx	Reorder	1,260
Dog Food	Dog Accessories	Pack	3 packs per Dog per 2 weeks	NIL	18	45	810	http://www.dog.com/item/natures-variety-raw-instinct-food-chicken-25-lbs	Reorder	810
Total for FIRST 30 days (USD$) (FY$08)						**$199,684.00**		Total for Next 30 days (USD$) (FY$08)		**$68,604**

Table 38: Cost Estimates for Search

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
CQB Standard Individual Operational Loadout										
Pencil Flare Kit	CQB Equipment	Piece	1 unit per person	Use an average of one flare per mission	50	.75	37.50	Expert - boarding	Reorder	38
MK-13 Flare	CQB Equipment	Piece	1 unit per person	Use an average of one flare per 3 missions	17	24.99	424.83	http://www.nextag.com/signal-flare/search-html?nxtg=c62d0a1c0527-40A18B127DA092F1	Reorder	425
Strobe Light W/IR Cover	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	34.95	3495	http://www.nextag.com/strobe-light/search-html	Nil	0
Battery Strobe Light Extra	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	5	500	http://www.nextag.com/strobe-light/search-html	Replace used batteries	50
Chemlight White High Intensity	CQB Equipment	Piece	3 units per person	Use one per person per mission. CYALUME® SNAPLIGHT® CHEM-LIGHT™ STICK HIGH INTENSITY 30 MINUTES	300	3.97	1,191	http://www.actiongear.com/cgi-bin/tame.exe/agcatalog/level3c.tam?xax=22538&nextrow=21&maxhits=10&qrymark1%2Enew=3252&qrymark2%2Enew=0&priorcase=main	Reorder	1,191
Chemlight I.R.	CQB Equipment	Piece	1 unit per person	2 per mission. CYALUME® CHEM-LIGHT™ STICK 6", 3-HOUR, INFRARED *RA*	100	3.99	399	http://www.actiongear.com/cgi-bin/tame.exe/agcatalog/level4c.tam?M5COPY%2Ectx=10670&M5%2Ectx=3206&siteID=uAGcup4ChO4-UBGlPwCv%2A89TTgYio	Reorder	399

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
								Y384g		
Signal Mirror	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	10	1000	http://www.google.com/products?client=safari&rls=en-us&q=signal+mirror&ie=UTF-8&oe=UTF-8&um=1	Nil	0
UDT Lifejacket	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	334.95	33,495	http://shop.navyseals.com/detail.aspx?ID=10&Name=Mustang-UDT-Life-Preserver	Nil	0
Bulletproof Vest W/ Plates	CQB Equipment	Unit (2564A Kit System, Vest, Flotation includes LBT-2564A, LBT-2563A, LBT-0250F, LBT-2525B, LBT-2500C, LBT-1933D, LBT-1609A, 10x12 Polyethylene Plate (set of two), and 5x7)	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	1595.88	159,588	http://www.adstactical.com/lawenforcement/TXMAS-7-84050.pdf	Nil	0

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
Bulletproof Vest Floatation Bladder	CQB Equipment	Unit (BlackHawK Tactical Float Vest II)	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	249	24,900	http://www.blackhawk.com/product1.asp?P=30TFV2BK&C=C1123	Nil	0
Gunshot Kit Waterproofed	CQB Equipment	Unit (Dyna Med® MOLLE Pouch Gunshot Trauma Kit w/ QuikClot™ ACS™+)	2 units per boarding team	Initial purchase of two per boarding team, plus some spares	20	70	1,400	http://www.galls.com/goid/style.html?assort=general_catalog&style=TK068&utm_source=froogle&utm_medium=datafeed&utm_campaign=Froogle-Datafeed&__skl_fd_skuid=TK068&__skl_fd_uan=1	Refills	300
I.V. Kit Waterproofed	CQB Equipment	Unit	2 unit per boarding team	Initial purchase of two per boarding team, plus some spares	20	20.50	410	http://www.atstacticalgear.com/istar.asp?a=6&id=TT-014!005	Refills	100
PRC-112	CQB Equipment	Unit	1 unit per team	Initial purchase of one per boarding team	15	6,348	95,220	http://www.gdc4s.com/news/detail.cfm?prid=188	Nil	0
Canteen 1 QT.	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	3	300	http://www.armynavyshop.com/Merchant2/merchant.mvc?store_code=army-navy-shop&screen=PROD&product_code=rc626	Nil	0
Canteen Pouch	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	12	1,200	http://www.armynavyshop.com/Merchant2/merchant.mvc?store_code=army-navy-shop&screen=PROD&product_code=rc633	Nil	0

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
Sit Harness Climbing (Special Operations Quick Repelling Harness)	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member, only one team (8) per vessel	40	61	2,440	http://www.armynavyshop.com/Merchant2/merchant.mvc?Screen=PROD&Product_Code=rc297&Category_Code=climbing-rappelling-gear&Product_Count=6	Nil	0
Snaplink Nonlocking	CQB Equipment	Piece (D Carabiner)	1 unit per person	Initial purchase of one per boarding team member	100	13	1,300	http://www.armynavyshop.com/Merchant2/merchant.mvc?Screen=PROD&Product_Code=rc277&Category_Code=carabiners&Product_Count=0	Nil	0
Zip Tie Large	CQB Equipment	Piece (175 lb. Extra Heavy Duty Cable Ties - Zip Ties)	4 per person	Initial purchase of 4 per boarding team member	400	.10	40	http://www.lecoplastics.com/zip-ties-Cable-ties.aspx	Reorder	40
Gasmask	CQB Equipment	Piece (SGE 400 gas mask)	1 unit per person	Initial purchase of one per boarding team member	100	119	11,900	http://www.approvedgasmasks.com/sge-400.htm	Mx	1000
Gasmask Filter Extra	CQB Equipment	Piece (M-95 NBC)		Initial purchase of spares, maintain enough for 3 boarding teams per vessel (12 teams of 8)	96	38.50	3,696	http://www.approvedgasmasks.com/filter-m95.htm	Replace used cartridges	500
Protect Helmet	CQB Equipment	Piece (Special Forces Kevlar Helmet)	1 unit per person	Initial purchase of one per boarding team member	100	250	25,000	http://www.bulletproofme.com/Body_Armor_Accessories_Helmets.shtml	Mx	1000

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
Knife	CQB Equipment	Piece (Smith & Wesson Extreme Ops Tanto Knife)	1 unit per person	Initial purchase of one per boarding team member	100	37	3,700	http://www.armynavyshop.com/Merchant2/merchant.mvc?Screen=PROD&Product_Code=rc3077&Category_Code=11-knives-tools-swords-weapons&Product_Count=6	Nil	0
Bungee Cord	CQB Equipment	Piece (18" Super Duty W/Hang)	6 units per team	Initial purchase of six per boarding team (12 teams)	72	1.50	108	http://www.lowes.com/lowes/lkn?action=productDetail&productId=18000-37340-2PT945&lpage=none	Nil	0
Flight Glove Pair	CQB Equipment	Pair	1 unit per person	Initial purchase of one per boarding team member	100	30	3000	http://www.google.com/products?client=safari&rls=en-us&q=flight+glove&ie=UTF-8&oe=UTF-8&um=1	Nil	0
Fastrope Leather Glove Pair	CQB Equipment	Pair	1 unit per person	Initial purchase of one per boarding team member	100	65	6,500	http://www.blackhawk.com/product1.asp?P=998056&C=C1912	Nil	0
Holster Quickdraw	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	124	12,400	http://www.blackhawk.com/product1.asp?P=43050&C=C2094	Nil	0
Magazine Pouch Sig P-226 Quickdraw (Digital camo MOLLE I 9mm mag pouches	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	14	1,400	http://www.armynavyshop.com/Merchant2/merchant.mvc?Screen=PROD&Product_Code=rc40120&Category_Code=military-pouches&Product_Count=18	Nil	0

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
CQB Assault Vest	CQB Equipment	Piece (Includes assorted ammo pouches)	1 unit per person	Initial purchase of one per boarding team member	100	737.61	73,761	http://www.awsin.com/oa/ie/iesub/cqb.htm	Mx	1000
Magazine MP-5N	CQB Equipment	Piece	7 units per person	Initial purchase of 7 per person	700	29.95	20,965	http://www.keepshooting.com/firearmaccessories/magazines/hk-mp5-mag-9mm-30rd.htm	Nil	0
Magazine Sig P-226	CQB Equipment	Piece	3 units per person	Initial purchase of 3 per boarding team member	300	42	12,600	http://www.sigsauer.com/Products/ShowCatalogProductDetails.aspx?categoryid=7&productid=191	Nil	0
Web Belt	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	29	2,900	http://www.blackhawk.com/product1.asp?P=41WB&C=C1204	Nil	0
Redlens Flashlight	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	16	1,600	http://www.armynavyshop.com/Merchant2/merchant.mvc?Screen=PROD&Product_Code=rc696&Category_Code=10-optics-lights-army-navy&Product_Count=3	Batteries	200
Plastic Bag Ziplock Large	CQB Equipment	Piece	4 bags per person	Use 50 per mission, 50 missions in 30 days	2500	0.10	250	SaveMart	Reorder	250
O.D. Triangular Bandage	CQB Equipment	Piece	3 units per person	Initial purchase of one per boarding team member	300	1	300	http://www.first-aid-product.com/industrial/triangular-sling-bandage.htm	Reorder	300
Magic Marker	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	2	200	http://www.sharpie.com/enUS/Product/Sharpie_Fine_Point_Permanent_Marker.html	Reorder	200

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
Hand held radio	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	2250	225,000	http://www.project25.us/index.htm (*Motorola XTS5000 VHF, Model III Portable)*	Nil	0
Nomex Flameproof Hood	CQB Equipment	Piece (DAMASCUS PROTECTIVE GEAR)	1 unit per person	Initial purchase of one per boarding team member	100	24	2,400	https://www.gsaadvantage.gov/advgsa/advantage/search/search.do?BV_UseBVCookie=Yes&op=0&rq=flare&find.x=0&find.y=0&sort=0&lmt=&vnd=&mf=&cat=ADV&act=refine&sk=9E7C2&q=00Tactical+Gear+Now	Nil	0
MP-5N	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	894	89,400	http://192.156.19.102/factfile.nsf/7e931335d515626a8525628100676e0c/20324744eaf1aba385256281005b3593?OpenDocument	Nil	0
SIG P-226	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	972	97,200	http://www.sigsauer.com/Products/ShowCatalogProductDetails.aspx?categoryid=7&productid=191	Nil	0
MP-5N Flashlight	CQB Equipment	Piece (Night-Ops Xiphos NT Weapon Mounted Light)	1 unit per person	Initial purchase of one per boarding team member	100	200	20,000	http://www.blackhawk.com/product1.asp?P=75204BK&C=C1784	Batteries	500
MP-5N Sling	CQB Equipment	Piece	1 unit per person	Initial purchase of one per boarding team member	100	49.99	4,999	http://www.blackhawk.com/product1.asp?P=70GS08BK&C=C1237	Nil	0

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
Protective Eyewear	CQB Equipment	Piece (BLACKHAWK HELLSTORM SPEC-OPS GOGGLES)	1 unit per person	Initial purchase of one per boarding team member, plus some spares	100	41.91	4,191	https://www.gsaadvantage.gov/advgsa/advantage/search/search.do?BV_UseBVCookie=Yes&op=0&rq=hellstorm&find.x=0&find.y=0&sort=0&lmt=&mf=&cat=ADV&act=refine&sk=C17DF&q=45GS-07F-8940D	Nil	0
Boarding Team Equipment										
Jacob's Ladder (Vertical Rope Ladder)	Boarding Equipment	Piece (rated for 700 pound rung loading, 2000 pound thimble loading)	1 unit per boarding team	12 boarding teams	12	1200	14,400	http://www.aclindustries.com/shipyard/vertical-ladders/rope-vertical-ladder.html	5% of Acq Cost for Annual O&S oost	720
Pilot Ladder	Boarding Equipment	Piece (Donaldson ladder, 9 m)	1 unit per boarding team	12 boarding teams	12	1200	14,400	http://www.donaldsonrope.com/pilot_ladders.htm	5% of Acq Cost for Annual O&S oost	720
Capewell Retractable Grappling Hook	Boarding Equipment	Piece (Constructed of high-strength steel Supports over 1,600 lbs Or Six 268 lb men Convenient Compact, Only 8-Inches High	1 unit per boarding team	12 boarding teams	12	199	2388	http://www.capewell.com/grappling%20hook.pdf	5% of Acq Cost for Annual O&S oost	120

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Requir ed	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumption	Next 30 Days Cost
T-PLS air-propelled tactical line-throwing system	Boarding Equipment	Set (A pneumatically launched tactical line-throwing system developed by DFT for Special Operations Forces. The T-PLS can launch a standard titanium grappling hook towing a 7mm Kevlar line in excess of 120 vertical feet using a regulated air source.)	1 unit per boarding team	12 boarding teams	12	1500	18,000	http://www.digitalforcetech.com/tpls.asp	5% of Acq Cost for Annual O&S oost	900
Total for FIRST 30 days (USD$) (FY$08)							**$999,998**	Total for Next 30 days (USD$) (FY$08)		**$9,953**

Table 39: Cost Estimates for Boarding

Item	Category	Accounting Measure	Units of Scale	Assumptions	Qty Required	Unit Cost / USD$	Total Cost FIRST 30 days / USD$	Reference	Assumptions	Next 30 days operation cost
Communications										
Camera	Collect information accessory	Pack	1 per boarding team	One time cost at purchase for Equipment	1	105	105	http://www.tigerdirect.com/applications/SearchTools/item-details.asp?EdpNo=3092931&CatId=130	Flash cards, batteries	40
Finger scanner	Collect information accessory	Pack	1 per boarding team	One time cost at purchase for Equipment	1	739	739	http://www.idville.com/details.aspx?PNO=46952&wtmcid=Y_OW_FGR_SCNNR&source=yahoo&WT.srch=1	Mx	50
FB500 satellite transceiver	External Comms equipment	Each	1 per mother ship	One time cost at purchase for Equipment	1	31,000	31,000	http://www.shop.gutsches.de/catalog/Kommunikation/Satellitentelefon/KVH-Tracphone-FB500/language/en.html	Mx	200
WetNET transceivers and antennas	External Comms equipment	Each	1 set per mother ship and 1 set per target ship	One time cost at purchase for Equipment	2	5,000	10,000	Not available in open source. Given figure is a ballpark estimate based on equivalent equipment.	Mx	150
Ruggedized laptop	External Comms equipment	Each	1 set per target ship	One time cost at purchase for Equipment	1	3,000	3,000	www.nextag.com. Cost of General Dynamics Itronix rugged notebook	NIL	0
Handheld Interagency Identity Detection Equipment	Biometric Equipment	Each	2 set per target ship	One time cost at purchase for Equipment	2	10,000	20,000	http://www.physorg.com/news124976279.html	Mx	100
Total for FIRST 30 days (USD$) (FY$08)							**$64,844**	Total for Next 30 days (USD$) (FY$08)		**$540**

Table 40: Cost Estimates for Communications

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XI. MODELING AND SIMULATION

A. INTRODUCTION

The purpose of this chapter is to provide high-level quantitative analysis of the relative effectiveness of alternative force structures within the context of the scenarios and Concepts of Operations (CONOPS) developed by the Operations Management group. Additional analysis is provided that supplements other chapters within this report. As has been described in the Systems Engineering section, beginning with the initial Functional Decomposition (FD) of the Maritime Interdiction Operation (MIO) task force, and following from the Measures of Performance (MOPs) and Key Performance Parameters (KPPs), several overall Measures of Effectiveness (MOEs) were identified that lent themselves to quantitative analysis by the MS group.

In order to perform the assigned tasks, the first step was to determine what modeling and simulation tools would be best suited to answer the questions presented by the Measures of Effectiveness (MOEs). A survey of the modeling and simulation tools that were available was conducted. The best tools available were determined to be MANA (Map Aware Non-uniform Automata) and NSS (Naval Simulation System). MANA was used to investigate the searching of ships of different sizes, how the search times were impacted by the use of two or three search teams, and the probability of finding contraband based on different sensor options. From a higher-level perspective of overall force structure alternatives, the Naval Simulation System (NSS) tool promised the best capability to a high degree of realism

B. NAVAL SIMULATION SYSTEM (NSS)

1. Background

NSS is an object-oriented Monte-Carlo modeling and simulation tool under development by Space and Naval Warfare Systems Command (SPAWAR) and

Metron, Inc. for the Chief of Naval Operations. NSS supports multi-warfare mission area analyses and is designed to support operational commanders in developing and analyzing operational courses of action at the mission, group, or force levels.

2. Modeling Description

The NSS tool allowed our analysts to define objects that interacted within the simulation environment, and further to simulate the nature of those interactions. Generally, this process begins by defining a command structure and then assigning assets to the various elements of that command structure. The assets available for assignment to the command structure can be copied from a pre-existing database of various platforms, including air stations, naval bases, ships, and aircraft; or they can be created according to the analyst's intentions. Once assets have been assigned to different command elements, they were further defined in terms of their motion within the simulation, sensor packages they carry, the communications and data processing capabilities they possess, and weapons they can employ. Further, each asset has its own susceptibility defined within the simulation, susceptibilities that make the asset detectable, identifiable, and classifiable to other sensor and weapon systems within the simulation. The behavior of the assets were defined by assigning tactics on several levels, including command level tactics and individual asset tactics. The behaviors and interactions among the various constructs within the simulation take place within a three dimensional geographical representation of the earth, which is definable by the analyst. Within this defined geographic area, the motions and tactics of the assets were further specified. At the initiation of a simulation run, a pseudo-random placement of assets within the scenario was initialized, along with initial tracking and identification information of those assets that fall within each other's spheres of awareness. At the start of the simulation, the assets move and behave according to the characteristics assigned to them by their individual asset characteristics, individual tactics, and command tactics. The analyst specified the duration of the scenario that was to be simulated.

The MOEs evaluated indicated relative effectiveness of different force structures in three different scenarios. The initial scenarios were built around the first phase of operations (Phase 0), and involved a maritime interdiction force attempting to locate and intercept a known high value vessel. The primary challenge faced by the force in this scenario was to pick out the suspect vessel from the neutral commercial shipping traffic. In these scenarios, the primary MOE was whether or not the suspect vessel was found. The second set of scenarios was built around the next phase of operations, Phase 1 (High Density). In this phase, the challenge presented is to interdict contraband that was being moved via surface vessels through an area where there was a high density of commercial shipping traffic and there was no knowledge of which vessels were carrying contraband. This situation dictated that the interdiction force intercept and search as many vessels as possible, with the resulting MOEs being the number of vessels searched. The third set of scenarios were built around a third phase of operations in which the traffic density was significantly lower than that in Phase 1 (High Density), which was called Phase 1 (Low Density). Again, the challenge for the interdiction force was to intercept and board as many vessels as possible, but, with the reduced traffic density, more time would be spent in transit between contacts, boarding efficiency would be reduced and the impact of intelligence, surveillance, and reconnaissance assets would be greater. Within each of the phases, different scenarios were built to compare the overall relative effectiveness as different assets are added to the interdiction force. The storyline that drives the different scenario excursions provided the rationale for the different force structures as well. In both phases of the operation, different allies might be available, each providing different assets to assist. The three scenarios along with the force structures are outlined below:

		Assets				
Scenario Number and Allies			Destroyers	Helicopters	Unmanned Aerial Vehicles	Maritime Patrol Aircraft
	1	US (no A/C) No Allies	2	0	0	0
	2	US (Helos) No Allies	2	4 (2 Airborne)	0	0
	3	US (UAVs) No Allies	2	0	6 (2 Airborne)	0
	4	US (UAVs) No Allies	2	0	6 (4 Airborne)	0
	5	US (Helos) and Green	2	4 (2 Airborne)	0	4 (1 Airborne)
	6	US (UAVs) and Green	2	0	6 (2 Airborne)	4 (1 Airborne)
	7	US (UAVs) and Green	2	0	6 (4 Airborne)	4 (1 Airborne)

Table 41: Phase 0 Scenario Breakdown

		Assets				
Scenario Number and Allies			Destroyers / Patrol Craft	Helicopters	Maritime Patrol Aircraft / Airborne Early Warning	Unmanned Aerial Vehicles
	8	US (UAVs) No Allies	3/1	0	0	9 (4 Airborne)
	9	US (Helos) No Allies	3/1	6 (2 Airborne)	0	0
	10	US (No A/C) No Allies	3/1	0	0	0
	11	US (UAVs)	4/1	0	4/0	12

		and Green			(1 P-3 Airborne)	(6 Airborne)
	12	US (UAVs) and White	4/1	0	0/4 (1 E-2 Airborne)	12 (6 Airborne)
	13	US (UAVs) and White and Green	5/1	0	4/4 (1 P-3 and 1 E-2 Airborne)	15 (6 Airborne)
	14	US (Helos) and White and Green	5/1	9 (3 Airborne)	4/4 (1 P-3 and 1 E-2 Airborne)	0

Table 42: Phase 1 (High Density) Scenario Breakdown

		Assets				
Scenario Number and Allies			Destroyers /Patrol Craft	Helicopters	Maritime Patrol Aircraft	Unmanned Aerial Vehicles
	15	US (No Aircraft) No Allies	3/1	0	0	0
	16	US (Helos) No Allies	3/1	6 (3 Airborne)	0	0
	17	US (UAVs) No Allies	3/1	0	0	9 (6 Airborne)
	18	US (Helos) and Green	3/1	6 (3 Airborne)	4 (1 Airborne)	0
	19	US (UAVs) and Green	3/1	0	4 (1 Airborne)	9 (6 Airborne)

Table 43: Phase 1 (Low Density) Scenario Breakdown

3. General Asset Characteristics

a. Destroyers

The core of the interdiction force was the destroyer (DDG), which is modeled after the US Arleigh Burke class DDG. For these simulations, a patrol speed of 15 knots (kts) and an intercept speed of 25 kts were assigned. The DDG has sensor capabilities which allowed it to detect surface contacts at 12 nautical miles (nm) and identify at 7 nm. Once the destroyer detected and intercepted the suspect vessel, it launched a boarding party which conducted the interdiction. In simulation-time this took at least one hour with an expected value of three hours.

b. Helicopters

Each destroyer in the simulation had the capability to launch the SH-60R Seahawk helicopter. This helicopter had a patrol speed of 120 kts. The sensors onboard the helicopter allowed it to detect surface vessels at a range of 60 nm, and identified those vessels at a range of 9 nm, at the assigned patrol altitude of 1000 feet. The helicopters were launched one every four hours for two hour sector patrol missions, resulting in 50% coverage by air assets. This assumption was based primarily on an anticipated crew-day for the aircrew.

c. Maritime Patrol Aircraft

In order to allow for the introduction of other force structures that could be evaluated against the baseline scenario, the scenario development efforts included allied nations along with the coalition. With the addition of Country Green to the scenarios, a Maritime Patrol Aircraft (MPA) became available to the MIO task force. The MPA was modeled after the P-3 Orion aircraft. This aircraft has the ability to detect surface targets at a range of 60 nm, and identify them at a range of 9 nm. The patrol was modeled as a ladder search at an airspeed of 200 kts and an altitude of 2000 ft. The P-3 maintained a patrol presence throughout the duration of any scenario of which it is a part.

d. Unmanned Aerial Vehicles

The unmanned aerial vehicles in these simulations were loosely modeled after vertical takeoff unmanned aerial vehicles (VTUAVs) currently under development by the US military. The primary differences between the helicopters modeled were reduced sensor capabilities and improved endurance. These helicpoters had the ability to detect surface targets at 20 nm, and identify them at 7 nm. They flew at 1000 ft and 100 kts. The UAVs launched every four hours on four-hour sector patrol missions, maintaining nearly continuous patrol presence throughout the scenarios of which they were a part.

e. Airborne Early Warning Aircraft

Another asset that might become available to the interdiction task force in later phases of operations was an Airborne Early Warning Aircraft, which was modeled after the E-2C Hawkeye. This aircraft has increased detection capability, but no identification capability, and serves as a communications relay center and data fusion center. These aircraft fly an orbit pattern in the center of the region of interest at an altitude of 28,000 ft. At this altitude, the E-2 can detect surface contacts at 200 nm, but has no identification capability.

f. Patrol Craft

The patrol craft introduced in the scenario with the addition of allies are identical to the destroyer in motion, sensors, and tactics. The only difference is that the patrol craft did not have the capability of deploying helicopters or UAVs.

g. Commercial Ships

The commercial ships modeled in these scenarios were built on a large cargo ship construct from the pre-existing database. They moved through the region of interest at 18 kts. In the Phase 0 scenarios, there were 200 commercial ships and a single hostile ship that was designated the suspect vessel. In the Phase 1 scenarios, there were 150 commercial ships and 50 'suspect vessels' carrying contraband. In Phase 1 (High Density) these vessels appeared identical to the interdiction force. In the Phase 1 (Low Density) scenarios, there was significantly less traffic, with ten commercial ships and only two suspect vessels in the scenario.

For a copy of the NSS scenario files and databases, please write to "Graduate School of Systems Engineering and Applied Sciences, Attn: Professor Gary Langford, Naval Postgraduate School, Monterey, CA 93940-5000"

4. Results

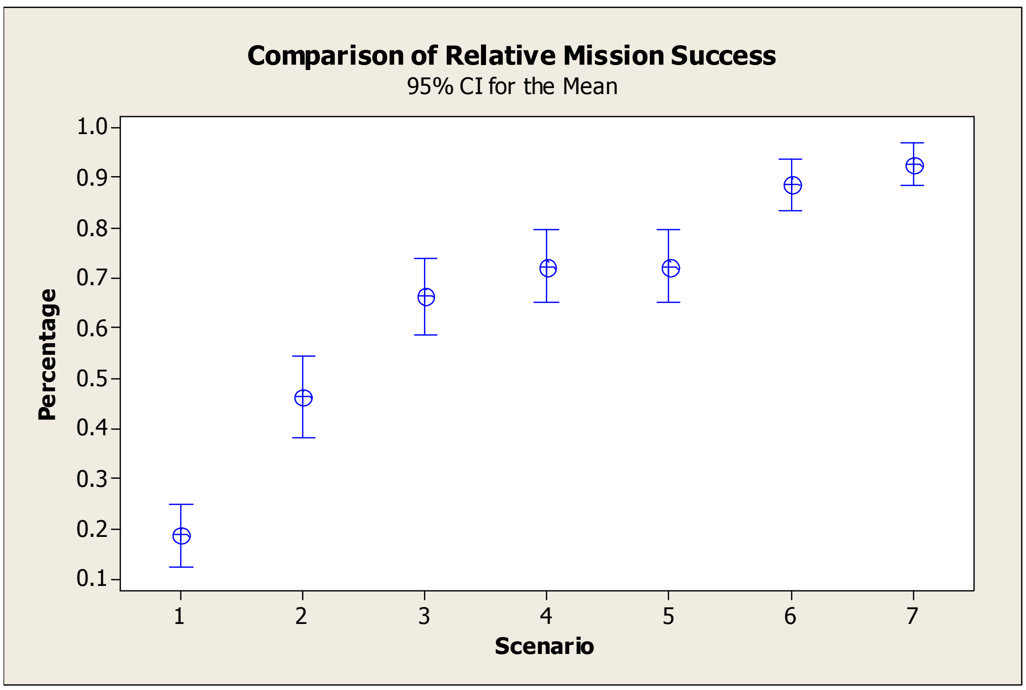


Figure 57: Phase 0 Relative Mission Success

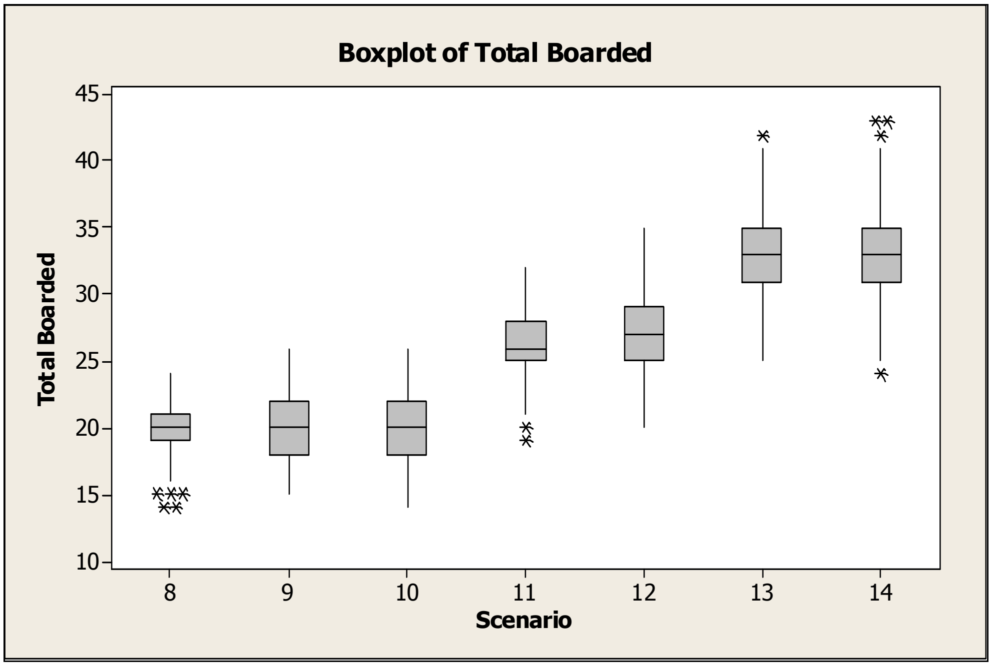


Figure 58: Total Number of Ships Boarded in Phase 1 (High Density)

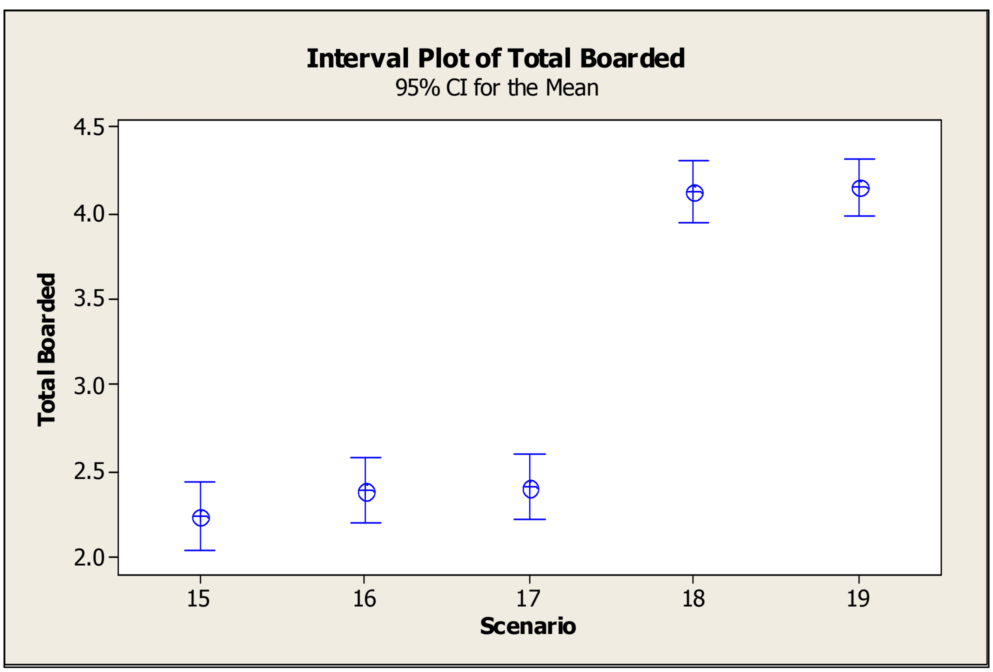


Figure 59: Total Number of Ships Boarded in Phase 1 (Low Density)

5. Analysis

a. Phase 0

The results presented in Figure 57, shows the vital importance of having aviation assets available to assist in this type of scenario. Keeping in mind that in Phase 0, the goal was to locate and intercept a known suspect vessel while operating in an area of high commercial traffic density. This Phase of operations also assumed there was highly reliable intelligence available on the identity of the target vessel. Scenario 1 showed the results of the simulation when there were no aviation assets available and the only way to detect and identify the suspect vessel was with the surface search assets available. With only two destroyers able to conduct the search, the key MOE, percentage of times the suspect vessel was found, was less than 30%. In Scenario 2, the inclusion of the ability to launch helicopters increased the rate of successful interception of the suspect vessel from 39 to 53 percent. While it was part of the reason that destroyers were so valuable in this type of operation, the inability to launch a helicopter highlighted the potential impacts of adverse weather and limited logistics support in this region.

The next important realization from the Phase 0 results was the relative value of UAVs versus helicopters and P-3s. From the differences between Scenarios 2 and 3, where the interdiction force changed from having two destroyers each operating a helicopter to two destroyers each operating a UAV, the impact of the UAV's greater endurance and lower maintenance requirements can be seen. While the helicopter had greater sensor capabilities, these capabilities were clearly outweighed by the greater availability of the UAV. This difference realized an effectiveness increase from 60 to 72 percent effectiveness.

While the UAV contributed significantly to the force effectiveness, the addition of multiple UAVs appeared to have very little impact. In scenario 4, the sortie rate of the UAV was increased so that at any given time, each destroyer had two UAVs conducting search patrols. This increased sortie rate only yielded a 6 percent increase in effectiveness. This was due to the fact that the addition of another asset was masked by the near continuous coverage afforded by the greater endurance of the UAV as well as the limited search range of the UAV.

In scenario 5, two helicopters were used for patrolling, but with “Country Green” added to the coalition. The addition of this country allowed access to an airfield, and with a Maritime Patrol Aircraft detachment stationed there. This detachment was able to provide the interdiction force with continuous coverage. As is shown here, two helicopters and a P-3 provide nearly the same effectiveness as two (or four) UAVs, with a success rate of 66 to 78 percent.

Scenario 6 and 7 provided the best overall interdiction force effectiveness for Phase 0. In these two scenarios, the effect of using UAVs combined with the P-3 was very distinct. In Scenario 6, the reduced sortie rate for the UAV along with the P-3 yielded a successful mission 84 to 93 percent of the time. In Scenario 7, with increased UAV sorties and the P-3, the success rate was 89 to 96 percent.

b. Phase 1 (High Density)

In Phase 1 (High Density), the simulations showed that in high traffic density areas, the availability of surface search assets was much more important than aircraft. In these scenarios, the high traffic density resulted in the search assets moving from one boarding to the next, rarely having to spend a significant amount of time looking for their next boarding. It was this phenomenon that led to the development and exploration of Phase 1 (Low Density). The Phase I (High Density) scenarios also included the addition of "Country White" to the coalition. As described in the Operations Management section, Country White made available an E-2 Hawkeye aircraft which had the ability to detect targets at long ranges, but since it typically operated at high altitudes, it was unable to identify targets. Country White also made available a surface patrol craft to assist in boarding operations, which was a critical element in these scenarios.

In Scenarios 8, 9, and 10, the mean number of vessel boardings was statistically the same, with a mean of approximately 20 vessels being boarded in each scenario. Among these three scenarios, the interdiction force consisted of three destroyers and one surface patrol craft, with the difference between the scenarios being the addition of two helicopters in scenario 9 and four UAVs in scenario 8. The only real discernible differences between the overall effectiveness of the three scenarios was the slightly wider spread in the data. The fact that the data was normally distributed both above and below the means reflected the lack of significant impact of aircraft in these scenarios.

In Scenarios 11 and 12, the addition to the coalition of Countries Green and White brought not only the availability of land-based aircraft, but also additional surface search assets. The increase from four to six surface search assets (along with their organic UAV assets) enabled the interdiction force to increase the number of vessels searched per 24 hour period from approximately 20 to approximately 27, a 35% improvement.

Scenarios 13 and 14 brought the total surface search assets available to the interdiction force up to six, a mix of five destroyers and one patrol craft. This increased the overall effectiveness of the interdiction force up to 33 vessel boardings.

c. Phase 1 (Low Density)

The results of Phase 1 (High Density) illustrated the fact that aircraft did not contribute significantly to the overall effectiveness of the interdiction force when the number of potential MIO targets greatly exceeded the capacity of the MIO task force. However, the addition of surface forces did linearly improve the success rate in those types of scenarios. This led to the question of aircraft relevance in a scenario where there were very few commercial ships spread over a very large area. These scenarios incorporate twelve ships in a 200 x 300 nm area. Five scenarios exploring this type of situation were presented.

In the first three scenarios of Phase 1 (Low Density), there were no maritime patrol aircraft involved in the search. The lack of this type of asset in such a large area with such widely dispersed targets was immediately apparent. Scenarios 15, 16, and 17 showed the interdiction force was only able to board 2.0 to 2.6 ships per 24 hours, with no statistical difference between the three scenarios, which differ only in the number of aircraft available that assisted in the search.

Scenarios 18 and 19 again showed the importance of having a long-range patrol capability with high on-station time. The addition of the P-3 asset in these scenarios nearly doubled the approximate number of vessels boarded in the scenario to 4.0 to 4.5 vessels boarded. While this was certainly a significant improvement over the scenarios without the P-3, the primary driving factor in these scenarios remained the great distances to be covered by the surface search assets.

6. Model Challenges and Limitations

NSS is a modeling tool that is still in development. The lack of a mature, tested tool created significant challenges throughout the learning and programming process that were not apparent at the onset of analysis with NSS. Particularly challenging was the reliability of the system. Initially, (through the programming phase), the system proved to be very stable, and there were few problems. However, once the task of running the simulations began, the system was subject to frequent crashes and lock-ups. These crashes and lock-ups caused not only the loss of data and programming work, but also required outside resources to reset the system, which commonly delayed the resumption of work by several hours.

Although NSS appeared to be extremely flexible and allowed the analyst to program whatever was desired, it ultimately was a combat engagement model that required several creative work-arounds before the team could simulate the required interactions. These work-arounds included the 'boarding-party' interaction, as well as representations of aircraft tactical responses and communications.

a. The Boarding Process

The 'boarding party' interaction was the first significant challenge posed by NSS. A representation of the time delay incurred by a search asset when it encountered and boarded a vessel was needed. Being primarily a combat model, NSS had the capability to replicate combat interactions using detection and identification sensors, weapons with varying degrees of accuracy and damage potential and targets of varying degrees of susceptibility. There was, however, no pre-programmed delay interaction that lent itself to representing the boarding interaction. In order to overcome this issue, the boarding interaction was represented as a combat engagement. First, a general period for each boarding (including transit and preparation) of approximately three hours was assumed. Then, an inverse binomial was built in Microsoft EXCEL™ that had three variables: number of shots, delay between shots, and probability of hit. Using these three variables, a distribution was built to replicate the time to search a vessel, with primary concern placed on the mean search time. The final distribution is shown in Figure 60. The parameters used were five hits required, ten minute delay between shots, and 0.255 probability of hit.

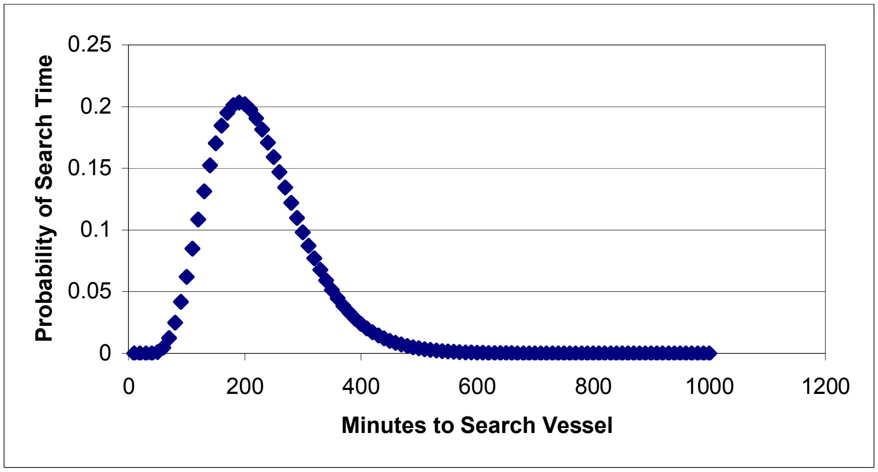


Figure 60: Vessel Boarding Time Distribution

Next, the team constructed a 'boarding party weapon' on board each of the searching assets with these same three parameters. Using this 'weapon' and building the interaction between it and the commercial ship being searched, a boarding was then modeled as an engagement. This engagement began once the interdiction force vessel closed to within two nautical miles of the target vessel and repetitively 'fired' the boarding party 'weapon'. This "trick" allowed the analyst to use the number of weapon misses and number of weapon hits to replicate and measure the mean search time.

b. Aircraft Behaviors and Tactics

The next significant challenge was the aircraft tactical behaviors. While NSS was incredibly proficient in ship based tactics, chain of command effects, etc., the behaviors of aircraft in real world MIO's were not readily available. Specifically, aircraft lacked the ability to track and trail a target. For example, if a P-3 Orion, in the simulation, were to identify a surface contact as hostile, the aircraft would not remain with that hostile target until a surface assets arrived. The P-3 simply continued along its search path and if the ship eventually dropped off the P-3's radar there was no guarantee that the MIO vessels would find the hostile vessel. This caused serious issues in Phase 0 simulations, where the entire force was searching for one suspect vessel. However, there was not a great impact on the Phase 1 scenarios where every vessel was suspect and having the MIO vessels simply proceed toward higher density areas of commercial traffic was enough.

To overcome this difficulty, a construct in the Phase 0 model called a relay was created. This was a ship with a large sensor swath width, covering all of the AOR, with a 20,000 ft mast to ensure no LOS issues with the RADAR. This ship was stationed in the center of the area of interest, but had no classification or identification capability. Therefore when the simulation started, the commander (an NSS construct) had a full "picture" of the area, but no classification or identification of any of the vessels, similar to a low-resolution satellite image. However, the relay had the ability to track targets once classified and identified by other vessels. If the P-3 flew by the red ship and then lost contact, the relay vessel would continue to track the red ship and vector the MIO vessels towards it simulating the P-3 staying on station.

This "trick" was only effective in Phase 0, since once the red ship was found there was no negative effect of the air assets continuing to search (because there were no more enemies). However, if this same model was used to search for two, three, or more enemy vessels, the aircraft tactics in NSS would have to be fixed and/or a different work around would have to be found.

C. MANA (MAP AWARE NON-UNIFORM AUTOMATA)

1. Program Details

a. Version

Version 4.00.1

b. Developer

MANA was designed by the Defence Technology Agency which is an agency of the New Zealand Defence Force.

c. *Description*

MANA is an agent based simulation (ABS), meaning that each entity in the simulation is controlled by decision making algorithms, instead of specific behaviors dictated by the programmer[63]. The primary advantage of MANA over larger physics based programs is the detail and high fidelity of MANA.[64] "MANA and similar programs are often called complex adaptive systems (CAS) because of the way the entities within them react to their surroundings. There are some common properties associated with MANA and other CAS combat models. First, the "global" behavior of the system emerges as the result of many local interactions. Second, CAS are an example of a process of feedback not present in "reductionist", top-down models. Third, CAS cannot be analyzed by decomposition into simple independent parts. The final common property is that agents interact with each other in non-linear ways, and adapt to their local environment.

2. Initial Approach

a. *Why MANA*

MANA was chosen for several reasons. It was felt that this type of combat model would be the best tool to investigate questions regarding ship boarding activities. The software is unclassified and therefore could be used by all members of the modeling and simulation team. Also, everyone within the MANA modeling team had a small amount of prior experience with MANA. Lastly, the MANA interface and output was simple.

Strengths:

- Simple user interface and output
- Easy to create terrain maps based on ship layouts

63 James W. Beaver and others, "Systems Analysis and Alternative Architectures for Riverine Warfare in 2010" (MS Diss, Naval Postgraduate School, 2006), 65

64 Ibid, 65

- Trigger states useful for simulating inspection times

Weaknesses:

- Model and output sometimes too simple when working on complex problems
- Agents do not easily navigate terrain resulting in the excessive use of waypoints
- Challenging to translate attributes of a urban warfare model to inspection of a ship

The MANA simulations generated were an attempt to create a complex adaptive system for important real-world factors of combat such as: spontaneous change of plans due to the evolving battle conditions, the influence of situational awareness on units when deciding on a course of action,[65] and the importance of sensors and how to best use them to gain an advantage.[66] Learning the basic interface takes little time, however certain limitations within the application can prove to be a hindrance for more complicated modeling needs. As such, the use of MANA in this study was meant as a low resolution, high throughput program.

b. What to Model and Questions to Answer

Simulating various ship boarding activities was initially considered because of a close relation to urban combat, for which MANA was designed. The modeling and simulation team looked into two distinct ship board scenarios.

Search: the simulation of ship search and inspection by the boarding party composed of task oriented teams. Several angles were explored to determine what scenarios best suited the MANA applications.

<u>Basic questions to be answered by search model:</u>

65 James W. Beaver and others, "Systems Analysis and Alternative Architectures for Riverine Warfare in 2010" (MS Diss, Naval Postgraduate School, 2006), 65

66 Ibid, 65

- How much time does it take to search a ship?
- Given there is contraband on board, what percentage of instances was it found by the boarding party?

Combat: the simulation of a boarding party encountering a hostile crew element, with conflict arising at the initial onset of boarding operations, or out of a subdued crew instigated by aggressor agents on the ship, resulting the sudden escalation of hostilities.

Basic questions to be answered by the combat model include:

- How many boarding party deaths occured when a ships crew becomes hostile?
- How much time did it take to neutralize the hostile crew?

c. Ship Variations

Two variations of ship layouts were modified into MANA terrain maps. All *Search* and *Combat* scenarios were run on both ship variations. A container ship with dimensions of 121 x 25 meters can be seen in Figure 61. Figure 62 shows the ship layout diagram for a 400 TEU RORO/LOLO Container Vessel built by Singapore Technologies Marine Ltd, which was the basis for the Container Ship. A Cargo Dhow with dimensions of 26 x 9 meters is shown in Figure 63. On these diagrams, the gray color represents areas where agents could not cross. The walls of the containers and outlines of both ships are gray representing where inspectors could not travel or cross. White represents terrain with no cover where inspectors could move easily. The pink area on the container ship diagram represents container spaces where movement was slightly slowly. Similarly, the light green and dark green on the cargo dhow represented the engine room and cargo areas that would be navigated slowly.

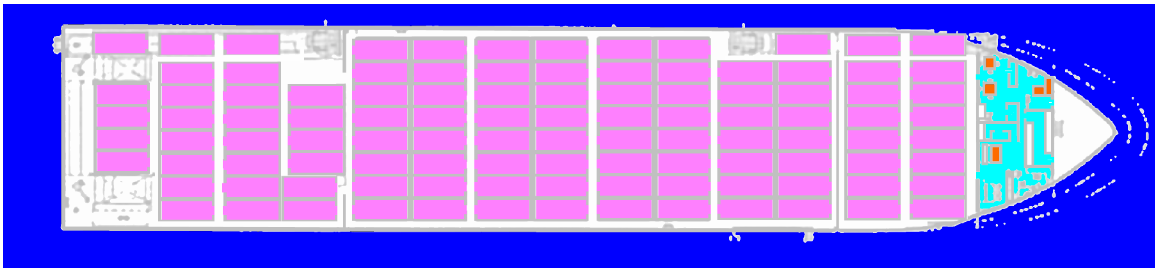


Figure 61: Container Ship (121 x 25 meters)

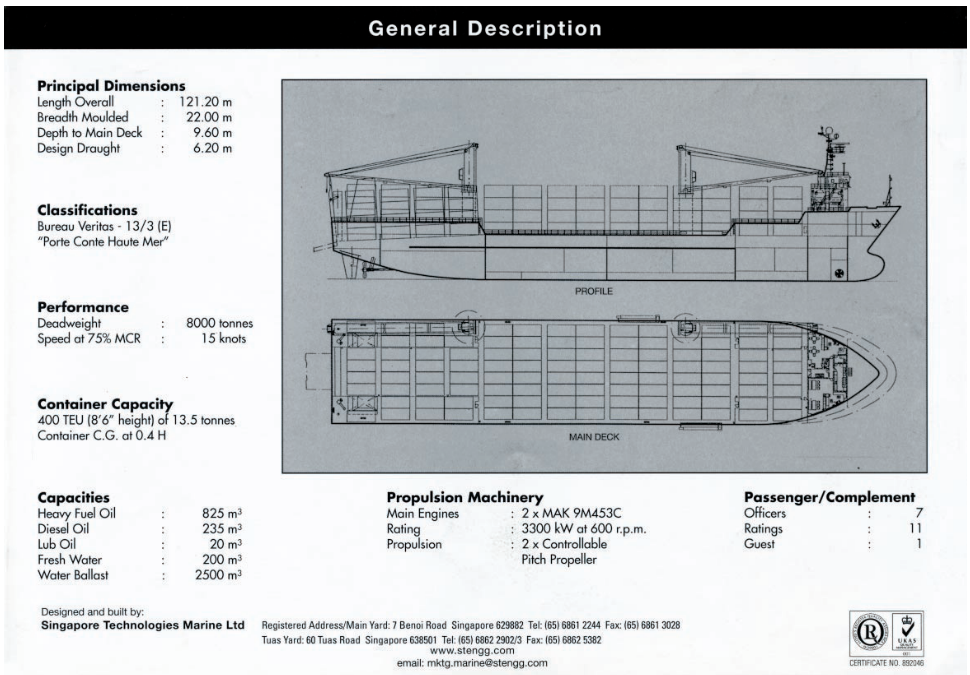


Figure 62: Actual Ship Layout Diagram by Singapore Technologies Marine Ltd

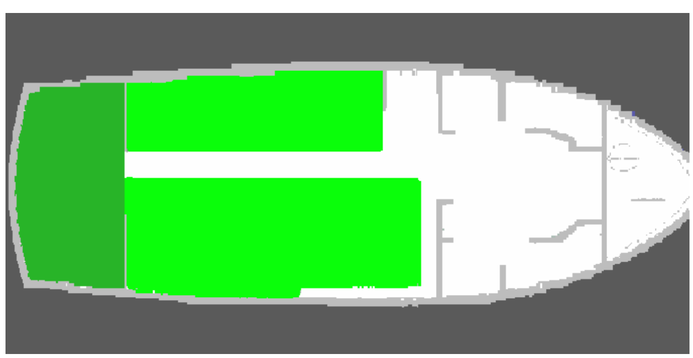


Figure 63: Cargo Dhow (26 x 9 meters)

3. Search Model

a. Overall Search Model Approach/Assumptions

A full factorial study with three sets of parameters was conducted. Parameters included whether or not it was a cargo ship or container ship under study, visual search versus employment of the Ion Mobility Spectrum (IMS) kit described in chapter VI, and the number of inspection teams (two versus three).

<u>Search Variables</u>

a) **Ship:** Cargo Dhow Container ship

b) **Sensor:** Visual search only IMS kit

c) **Search Team:** 2 teams of inspectors 3 teams of inspectors

Table 44: Search Permutations

Search Permutation #	Ship Type	Sensor	# of Search Teams
1	Cargo Dhow	Visual (Eyeballs only)	2
2	Cargo Dhow	Visual (Eyeballs only)	3
3	Cargo Dhow	IMS	2
4	Cargo Dhow	IMS	3
5	Container Ship	Visual (Eyeballs only)	2
6	Container Ship	Visual (Eyeballs only)	3
7	Container Ship	IMS	2
8	Container Ship	IMS	3

Differences in the layout of the two ships were explained in the previous section (2.c.) and were applicable to the *Combat* model.

Sensor comparisons were made between an IMS based contraband detector and a baseline visual search, with the inspectors' performing visual searches. The IMS sensor could only detect explosives and drugs. Therefore, it was important to note the contraband being considered is either drugs or explosives. While visual search could clearly indentify any type of contraband it was only compared to the IMS abilities. For modeling purposes, the entire process of making one IMS swipe/scan was assumed to take forty seconds with no deviation. The forty second time accounted for twenty seconds to take the swipe and twenty seconds for analysis, and was considered as an upper limit. The twenty second IMS analysis time was based on research done by the Search Team (Chapter VI). Visual search characteristics for the container ship and cargo dhow were modeled somewhat differently as a result of specific searching methods inherent to each type of ship. These differences are explained later.

The search team variable compared two versus three teams of inspectors. Each inspection team consisted of a pair of inspectors. Based on input from SEA-13 members experienced with MIO operations, two and three teams were modeled in order to be as realistic as possible. In practice, out of a given boarding party of eight individuals, two would detain the crew and two would interview the captain. This left two pairs of individuals to do the actual inspection. Therefore, a larger boarding party of ten members would result in three inspection teams. The remaining non-searching members of the boarding party were not simulated as their actions were assumed to have little effect on a physical search of the ship.

Details about the models are best explained by breaking the models into the "Container Ship Search Model" and the "Cargo Dhow Search Model".

1. Cargo Dhow Search Model Approach/Assumptions and Measures of Effectiveness

The cargo dhow search model was comprised of the first four permutations seen again in Table 45:

Table 45: Cargo Dhow Permutations

Search Permutation #	Ship Type	Sensor	# of Search Teams
1	Cargo Dhow	Visual (Eyeballs only)	2
2	Cargo Dhow	Visual (Eyeballs only)	3
3	Cargo Dhow	IMS	2
4	Cargo Dhow	IMS	3

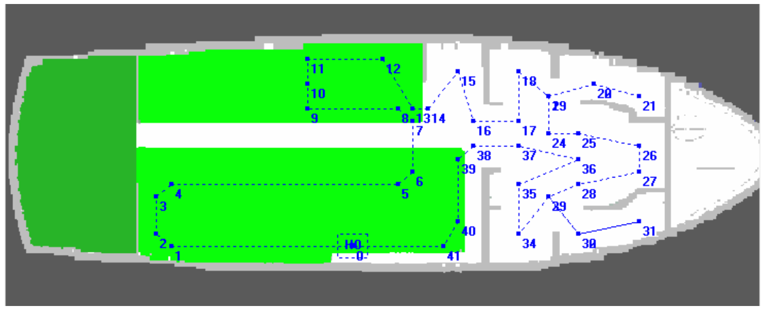
Three Measures of Effectiveness were considered for the "Cargo Dhow Search Model."

1) Time to complete search of the Cargo Dhow
2) Percentage of ships carrying contraband that was discovered
3) If contraband found, distribution of time to find contraband

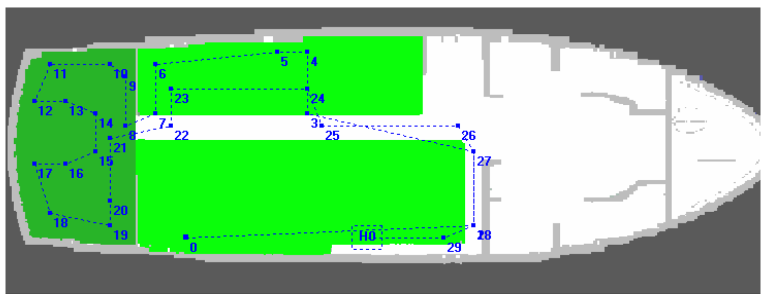
1.1 Cargo Dhow Visual Search

NOTE: All screen shots of MANA displayed in the following figures are taken from the "Visual Search, 2 Inspection Teams" model.

In the visual search models, it was assumed that the search teams would split up the search areas equally. The search path was drawn arbitrarily to cover as much ground as possible without losing practicality. The search path for the “Visual Search, 2 Inspection Teams” model variation is shown in Figure 64.



(a)



(b)

Figure 64: Search Path for (a) Team 1 (b) Team 2

A screen shot of the personality settings for the search teams using visual search is shown in Figure 65. Each personality setting can range from -100 to 100. For example, +100 for the “Enemies” means agents would have an affinity to be drawn to enemies. A -100 for “Enemies” indicates agents would stay away from enemies. To ensure each search team would stay in its own search areas, higher weighting was assigned to “Next Waypoints”. The “Uninjured Friends” setting was given a weighting of 50, so that the two individuals within a team would more than likely stay together during the search. In order to more realistically model the search process it was assumed inspectors would stop and examine certain areas closely for a small amount of time. These *Points of Interest* (POI) represented an inspector opening a closet, moving a heavy object, or closely scrutinizing a particular area. *Points of Interest* (POI) were simulated as immobile enemies. “Enemy Threat 2” (POI) inspector attraction was set to 10 so that the search team would approach POI once they detected it, while “Enemy Threat 1” (contraband) was set to 20 so the search team would approach the contraband once detected. It was assumed that the search team would tend to approach contraband more than POI if both were detected at the same time. This explains the difference between the weighting set for Enemy Threat 1 & 2.

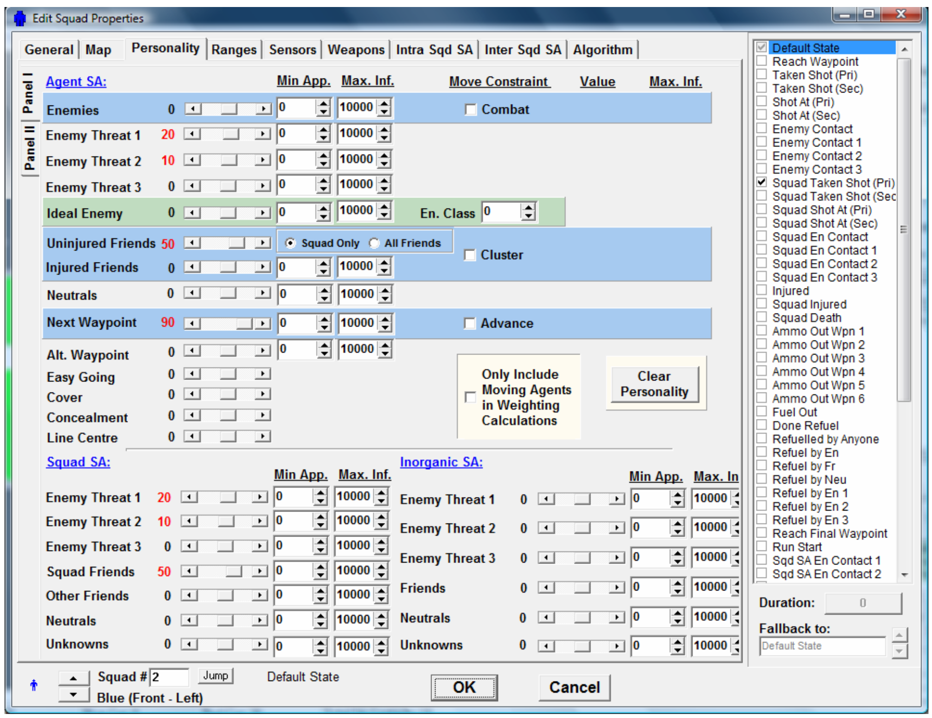


Figure 65: Personality of Search Teams Using Eyeballs

The “Ranges” tab for the search team is shown in Figure 66. The movement speed was set as 4/100 (0.04) grid square per time step, which is equivalent to a movement speed of 75 meters per hour. This speed was significantly slower than the normal walking speed of a human. However, it was assumed that it was extremely difficult for the search teams to maneuver in fully loaded cargo dhows, where there is no proper footpath and the teams would need to climb up and downs to access areas of interest. It is important to note that while this search speed may not be indicative of the search speed of teams under all circumstances, is was used as a mean time across a variety of circumstances. It is also important to note that this rate of movement was chosen to provide a basis for comparison of the other factors which impact the time to search. It would be possible to model different search times to reflect different scenarios, i.e. pre-boarding intelligence, search techniques, etc., but due to time and resource constraints, only this search speed was used.

Sensor height was set to 2 meters, which is a close approximation of human height. When no POI or contraband were present the search team would turn their heads around at a slew rate of 90 deg per second.

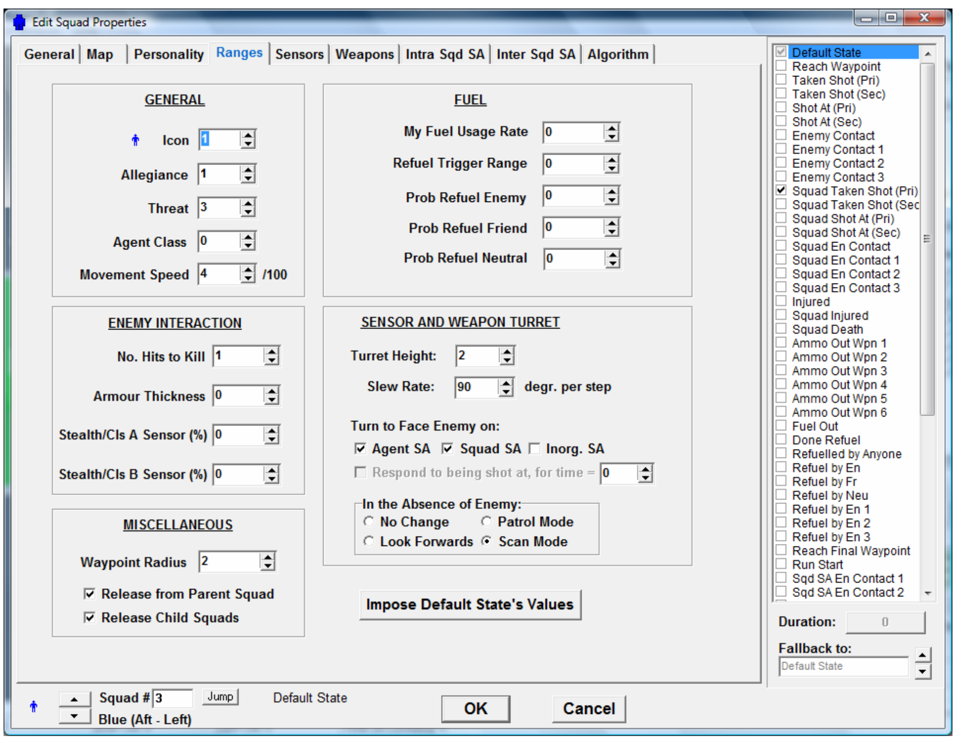


Figure 66: "Ranges" tab for Search Teams Using Eyeballs

The sensor settings are shown in Figure 67. The sensor was modeled after the capability of human eyes to detect and classify objects at a distance of 12.5m (24 grid squares) with a probability of detection of 40%, derived from research in chapter VI. Other sensor classification characteristics were determined with the assumption that human eyes would be able to classify objects with greater accuracy as they moved closer, with a 95% chance of classifying them at the range of 3 meters. The “Detect” setting was modeled on the input that human eyes needed 15 sec of processing time. It was also assumed that human eyes had an aperture angle of 180 degrees facing the front.

The acuity = 1.7 when the light level was greater than about 0.1 Lambert. A Lambert (luminance) was equal to 1/pi candela per square centimeter. A point source of one candela intensity radiates one lumen into a solid angle of one steradian. Thus, one needed two pixels per line pair, and that means a pixel spacing of 0.39 arc-minute. This assumed there was sufficient light to activate the cones in the eye, equivalent to daylight background luminance. So, it depended on the size of the object, the contrast of the object, the lighting conditions, and the dark adaptation coefficient of the eye.

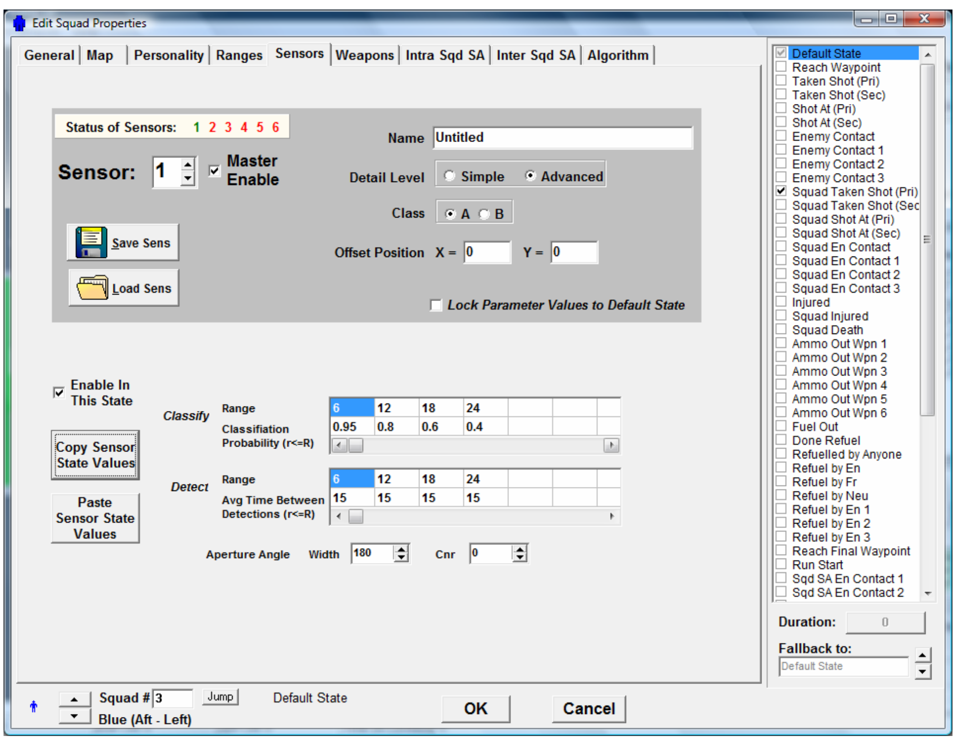


Figure 67: Sensor Settings of Search Teams Using Eyeballs

The weapons settings are shown in Figure 68. It was assumed the inspector would search (shoot) the POI or contraband within a 1 meter radius (two grid squares).

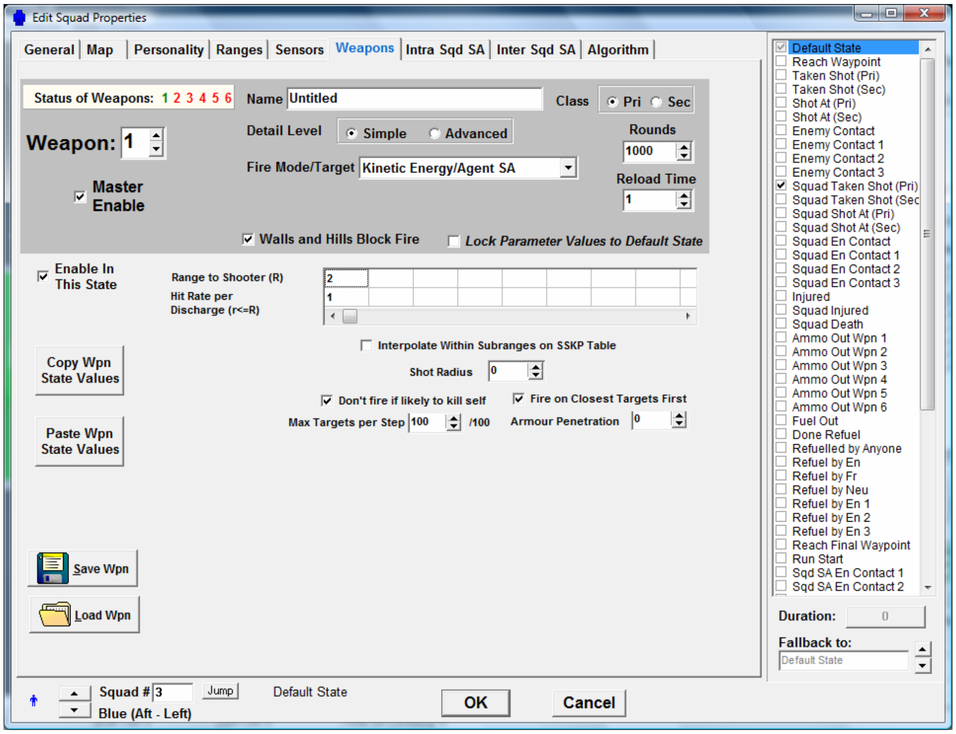


Figure 68: Weapons Settings of Search Teams Using Eyeballs

Once again, *Points of Interest* (POI) were randomly placed targets in the Cargo Dhow to simulate areas of which the search teams would pay more attention. The POI were configured to be spaced out evenly with a minimum of 1.5 meters (three grid squares) from each other. Two placement areas were defined for the POI so as to prevent MANA from placing them on the middle foot path. Thirty POI were simulated.

Contraband was randomly placed in the cargo areas or engine room. The placement areas specified were slightly different from that for the POI, as it is assumed traffickers of contraband items would try to hide their items in highly concealed locations, which was among the cargo or in the engine room. Only one contraband item was simulated.

The trigger states provided by MANA were used to model the search time required per POI. During the search, the inspection team would be immobilized for a uniformly distributed 2 to 4 minutes (120 - 240 steps) while inspecting each POI.

The “Visual Search, 3 inspection Teams” was very similar to that of the “Visual Search, 2 Inspection Teams,” except the search path was covered by three teams instead of two. Obviously, the addition of one more inspection team resulted in less area to cover for each individual team.

1.2 Cargo Dhow IMS Search

The “Cargo Dhow IMS Search” models were similar to the “Cargo Dhow Visual Search” models except for the following changes:

- Change of sensor characteristics and trigger states to model that of an IMS sensor instead of visual search
- Each team was only allocated one IMS sensor, and for modeling simplicity the two man teams were modeled with one agent
- Swipe locations replaced POI (explained below)

As with visual search, IMS was simulated by using multiple trigger states. Swipe locations were simulated much like the POI categorized under enemy status. Upon reaching a swipe location the inspecting agent shot and killed the swipe location (which from the inspecting agents’ view was a weaponless, defenseless, stationary enemy). After “shooting” and “killing” the swipe location the inspecting agent stood still for forty seconds simulating time for the entire swipe/scan process. After standing still the agent acquired a sensor for one second that could detect the contraband with a probability of detection of 95%. These time and probability parameters were derived from the Search

Report (Chapter VI). The sensor was assumed to be perfect with respect to false alarms. If no contraband was detected the agent returned to its default state. However, if there was a positive detection then the inspector changed trigger states and sought the detected contraband.

The "IMS Search, 3 Inspection Teams" model was similar to the "IMS Search, 2 Inspection Teams" model except for the search paths, which were the same as their respective "Cargo Dhow Visual Search" variations.

2. Container Ship Search Model Approach/Assumptions and Measure of Effectiveness

There were many similarities between the "Container Ship Search Model" and the "Cargo Dhow Search Model," however; there were also some unique differences. Container ships had multiple levels of containers stacked on top of each other. For the purpose of simplifying the model only the first deck of level containers were considered. It would be expected that any level above the first would take much more time to inspect due to the necessity of ladders or climbing equipment. Another difference was the distribution of cargo and increased number of locations for hiding contraband. The majority of the time a Cargo Dhow might have bags of rice or other random cargo stacked up in piles out in the open. On container ships everything is in individual containers. The detailed assumptions that go along with the container ship will be explained in the following sections. The "Container Ship Search Model" is comprised of the last four permutations seen again in Table 46:

Table 46: Container Ship Permutations

Search Permutation #	Ship Type	Sensor	# of Search Teams
5	Container Ship	Visual (Eyeballs only)	2
6	Container Ship	Visual (Eyeballs only)	3
7	Container Ship	IMS	2
8	Container Ship	IMS	3

There was only one Measure of Effectiveness considered for the "Container Ship Search Models":

- Time to complete search of the first level of containers

Unlike the "Cargo Dhow Search Model," percentage of ships discovered with contraband was not determined because of the assumption that inspecting teams would be searching each container. Thus, whatever probability of detection was given to the visual and IMS sensors would be the resultant percentage of ships found More simply stated, if the agents have a 95% probability of detection and every container is searched then the contraband would be found 95% of the time. This differs from the Cargo Dhow search which was more literally modeled in which agents had a 95% probability of classification only if they were looking at the specific location of the contraband.

2.1 Container Ship Visual Search

For the visual search it was assumed that each container on the first level would be opened and inspected quickly. The entire time spent opening, closing, and inspecting each individual container was assumed to be uniformly distributed between six and ten minutes. This distribution of time was determined by SEA-13 team members, some with experience of ship boarding and searching. The visual search was basically simulated by placing POI within each container. Agents needed to be precisely guided when a lot of edges and corners existed. As a result, the model was waypoint intensive which reduced overall randomness within the model. One inspection team's set of waypoints can be seen in Figure 69. Also seen in Figure 69 the insides of the containers were triangles. This modification to the original layout was necessary to prevent agents from getting stuck, however it did not detract from proper implementation of the model. Movement speed was set at 73/100 equivalent to 2 miles/hr, which is a slow walking pace.

The distribution of time spent per container simulates a variance in opening time and the level of detail the search team decided to spend on the inspection of a particular container. Points of interest for inspection were once again modelled as enemy squads that could not move. It was important to note POI in this model served more as a method to represent the random searching time of each container, which was slightly different than the more literal intent of POI in the cargo dhow model.

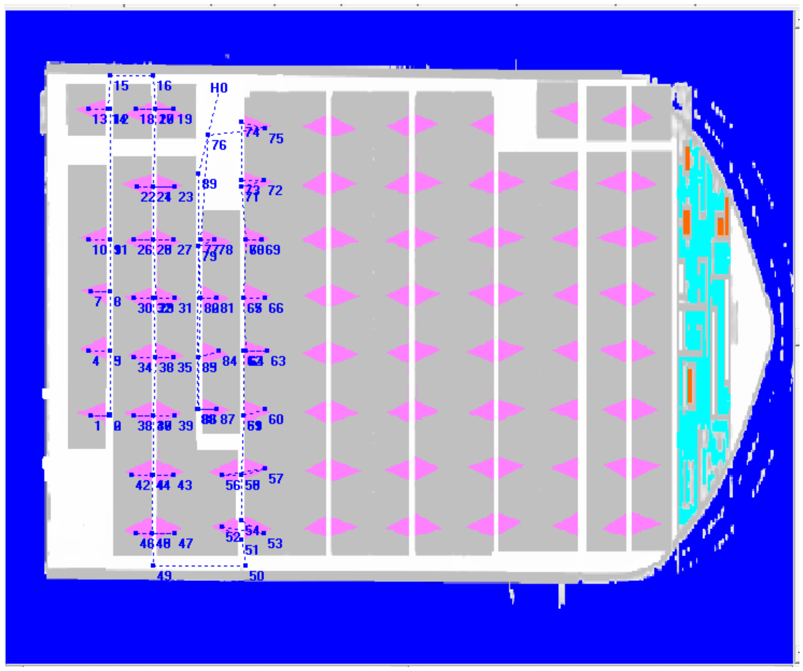


Figure 69: Container ship waypoints for one inspection team

2.2 Container Ship IMS Search

A swipe location was placed outside of every container. Waypoints were set up to guide the inspection teams to all swipe locations outside all containers. One inspection team's set of waypoints can be seen in Figure 70. Using IMS equipment, the inspection team was not required to open and search each container. Hence, the search process was more efficient. Movement speed was at 73/100 which was about 2 miles/hr, same as visual search speed. Detection range at 3 pixels was sufficient to ensure all swipe locations (simulated the same as in the cargo dhow model) are visited. When the inspection team engaged each swipe location, it triggered a delay which simulates the swipe/scan time of 40 seconds (same as cargo dhow parameters).

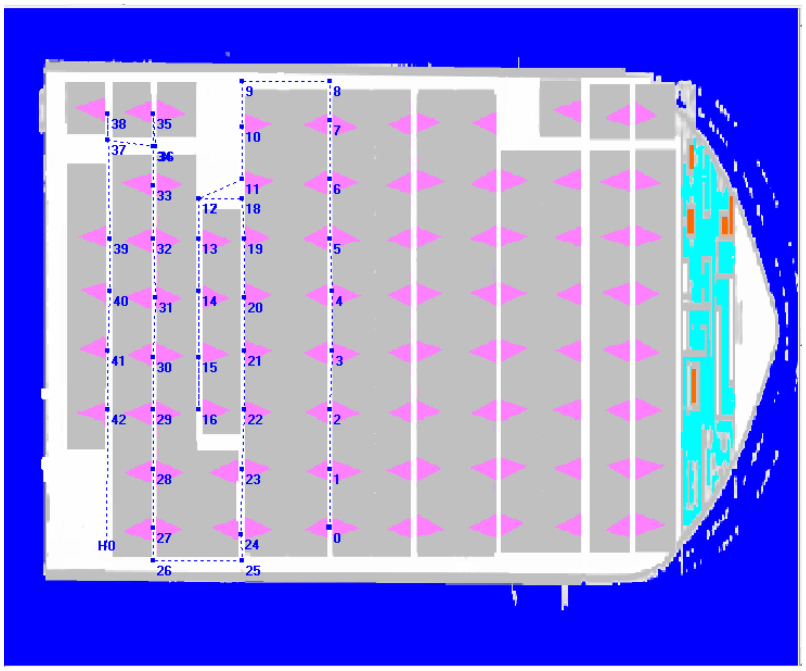


Figure 70: Container Ship IMS Search waypoints

c. Results/Analysis

1. Cargo Dhow Search Model Results

Significant assumptions that greatly affect modeling results for the "Cargo Dhow Search Models" were as follows:

- Number of POI and time to inspect each POI (visual search, 30 POI, 2 to 4 minutes uniformly distributed each)
- Number of swipe locations and analysis time (IMS search, 30 swipe locations, 40 second analysis time)
- Probability of detection for both visual search and IMS search (95% for both visual and IMS, however, terrain cover handicaps visual search abilities)
- Inspector's movement speed (75 meters per hour)

Whether or not the reader agrees with the significant assumptions made, the important take away when viewing the results is the relative difference between the four sub-models. Assumptions were kept the same in each model except for the necessary modifications inherent to each independent variable being compared. The "Visual Search, 2 Inspection Teams" model were considered to be the baseline scenario. Table 47 shows the results for the primary Measures of Effectiveness. Figure 71 and Figure 72 graphically show the results for mean time to search the cargo dhow and percentage of runs contraband was found, respectively. Close to what would be expected, employment of a third inspection team took approximately 70% of the time it took two inspection teams. The use of IMS lowered search time to approximately 70% of the baseline visual search inspection time. When both the IMS and a third inspection team were employed, inspection time was halved compared to the baseline visual search with two inspection teams. The low detection percentage for both visual searches was due to the low detection parameters set in the model, corresponding to the difficulty of finding concealed contraband. Once the IMS sensor detected the contraband the agent's personality was changed to only seek out the contraband, rather than continue to follow waypoints or inspect other POI.

Table 47: Cargo Dhow Search Model Results

Cargo Dhow Search Model Results *(Sample of 30 runs)*	Mean Time to Search Cargo Dhow with 95% CI	Percentage of Runs Contraband was Found with 95% CI
Visual Search, 2 Inspection Teams	105.8 ± 0.4 minutes	36.7 ± 17.2 %
Visual Search, 3 Inspection Teams	77.1 ± 0.3 minutes	36.7 ± 17.2 %
IMS Search, 2 Inspection Teams	77.5 ± 0.5 minutes	93.3 ± 17.2 %
IMS Search, 3 Inspection Teams	54.1 ± 0.3 minutes	76.7 ± 17.2 %

Note the small 95% confidence interval for search time. The lack of deviation is most likely due to the movement of agents, which was highly dependent on waypoints. As discussed earlier, agents had to be closely guided in order to not get caught on edges or in corners. Movement becomes less random as the number and proximity of waypoints increase. In real boardings there would be far more deviation in inspectors actions.

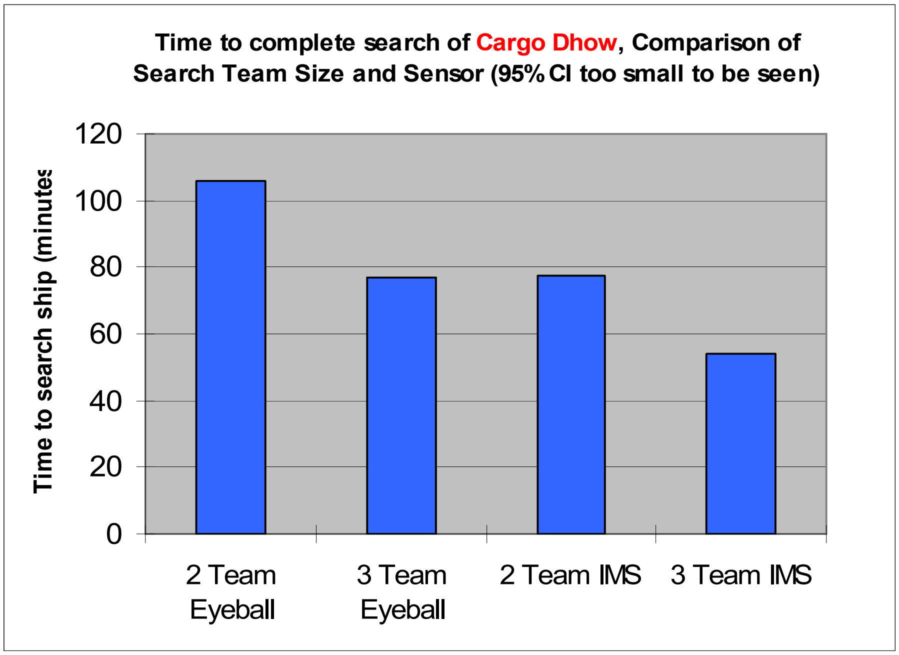


Figure 71: Time to Complete Search of Cargo Dhow

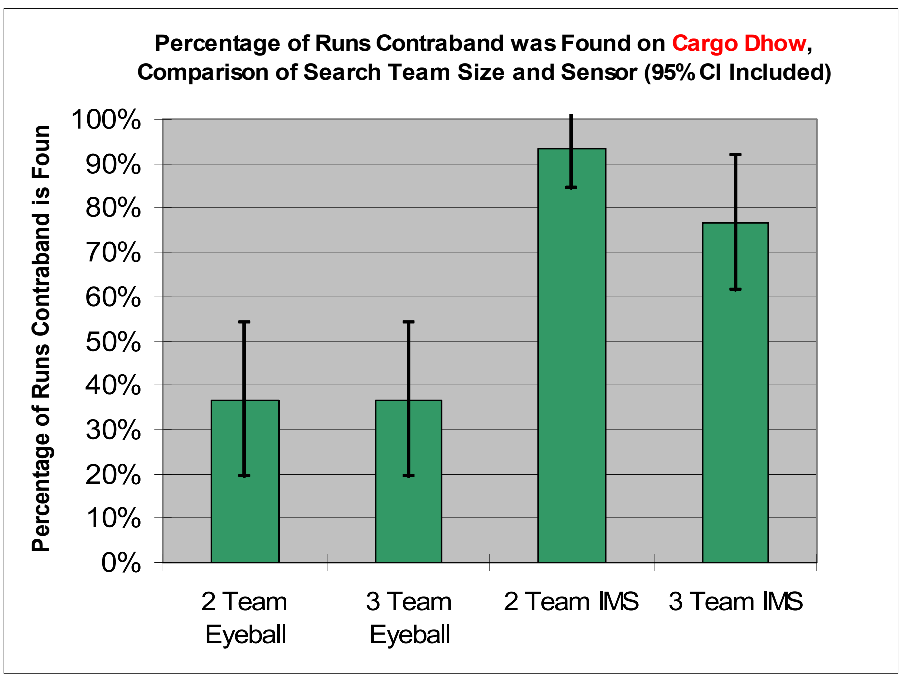


Figure 72: Percentage of Runs Contraband was Found on Cargo Dhow

Figure 73 through Figure 76 shows histograms of an additional MOE that was considered. Time when contraband was found is of importance when considering maritime interdiction operations in which the inspecting force turns over violators to a host country. Search times would be shorter considering once one contraband item was found, the search is over. Obviously, there would be ships which do not have any contraband that get searched, which would further complicate approximating ship's search time. The results are very random for all four models which makes sense. Depending on where the contraband was placed and where inspectors start searching, illicit goods can either be found early or late into the search.

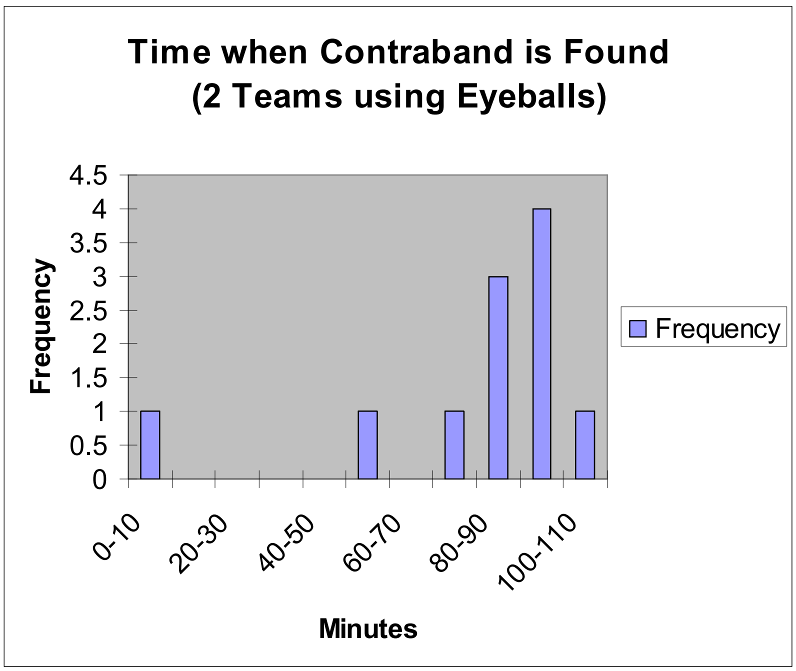


Figure 73: Time when Contraband is Found (2 Teams, Visual)

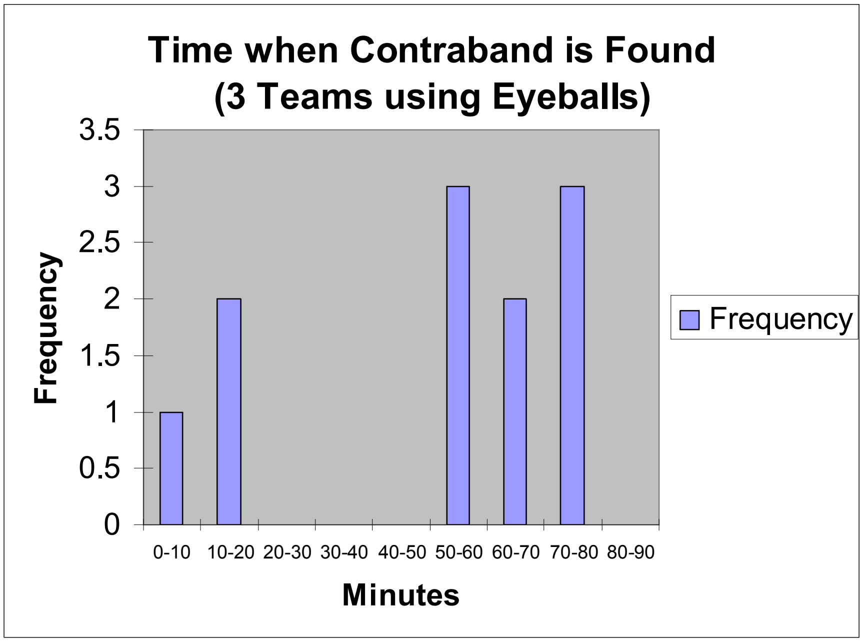


Figure 74: Time when contraband is found (3 Teams, Visual)

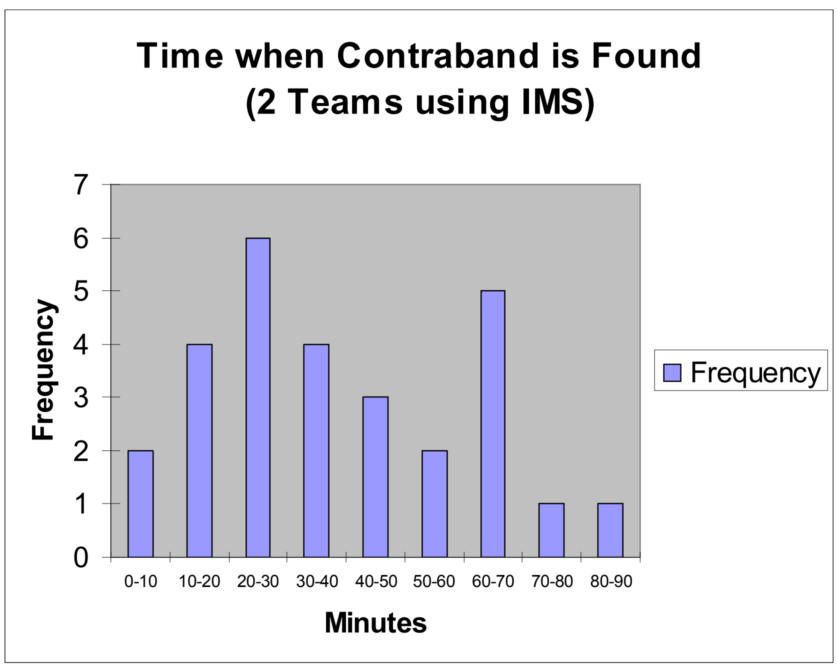


Figure 75: Time when Contraband is Found (2 Teams, IMS)

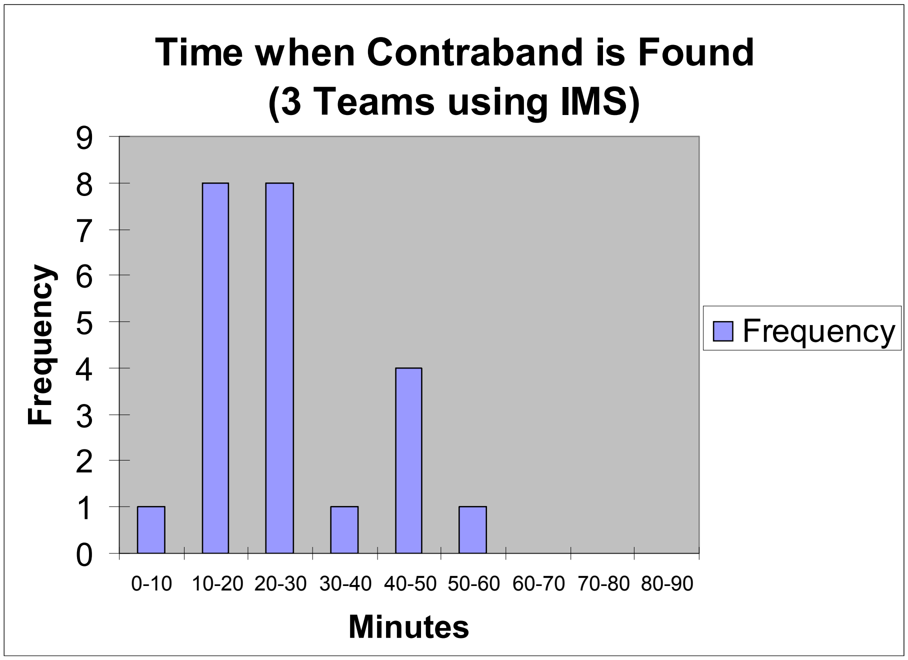


Figure 76: Time when Contraband is Found (3 Teams, IMS)

2. Container Ship Search Model Results

Significant assumptions that greatly affect modeling results for the "Container Ship Search Models" were as follows:

- Distribution of time to search each container (visual search, six to ten minutes uniformly distributed)
- Swipe locations placed outside of every container (IMS search, simulates each container being swiped)

Table 48 shows the results from the container ship search model. Figure 77 graphically shows the same results for mean time to search the container ship. The addition of one more inspection team continued to result in a search time 70% of the baseline time using two inspection teams. There was a vast improvement in search time when using the IMS sensor. Search time using IMS was approximately one eighth of the baseline visual search time. Due to both the larger size of the container ship and necessity to visually inspect each container, the improvement in search time using IMS was much more prevalent for the Container Ship. It was important to note these results are highly dependent on the specified time to open and inspect containers.

Table 48: Container Ship Search Model Results

Container Ship Search Model Results *(Sample of 30 runs)*	Mean Time to Search Container Ship with 95% CI
Visual Search, 2 Inspection Teams	7.91 ± 0.06 hours
Visual Search, 3 Inspection Teams	5.26 ± 0.08 hours
IMS Search, 2 Inspection Teams	0.91 ± 0.06 hours
IMS Search, 3 Inspection Teams	0.64 ± 0.02 hours

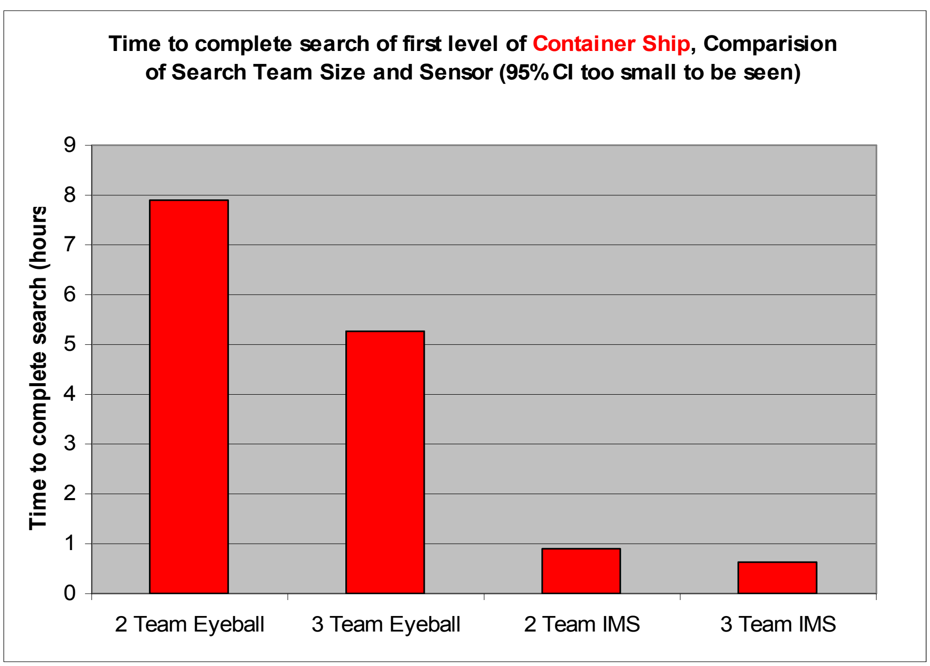


Figure 77: Time to Complete Search of First Level of Container Ship

d. Further Study

Adding probabilities of false detections would be an excellent addition to the search models. Sensitivity analysis on specified parameters was not done here but may provide greater insight. A different modeling program might prove more capable than MANA.

4. Combat Model

a. Combat Model Approach

Combat was simulated using MANA by means of implementing a force- on-force approach of red hostile elements attacking a blue force that had been inserted onto the ships. The combat model was simulated on both the Container Ship and the Cargo Dhow. A total of ten boarding team members and ten hostile ship crew members were modeled under the scenarios involving the Container Ship. A total of four boarding team members and six hostile crew members were modeled under the scenarios for the Cargo Dhow. Two conditions were created; one for the Container Ship and another for the Cargo Dhow. The scenarios created are as follows:

1) **Initially Subdued Crew**: the initial processing of the ship's crew escalated into a hostile situation. A portion of ship's crew was initially mustered under the watch of a guarding force. The boarding party interrogated the captain of the ship. Two hostile agents engaged the boarding party at first opportunity. Once a gunshot occurs, the mustered crew entered an aggressive state and attacked the boarding team personnel located at their location.

2) **Initially Hostile Crew**: the boarding party performed a dynamic insertion into the ship with a hostile crew of armed agents. For methodical purposes, the initial process of insertion is omitted. The boarding team conducted movement to contact the hostile crew members, neutralizing them. The scenario ended when all ten elements are neutralized.

b. Combat Model Approach/Assumptions and Measures of Effectiveness

For the purpose of the combat model, a series of assumptions were made with respect to the boarding team and the hostile elements:

Boarding Team: Boarding team members were modeled to have assault rifles with a 30 round capacity and an additional 30 rounds of ammo. Body armor was selected with settings designed such that each blue element needed 2 hits to be killed. Movement speed was set to 3 km/hr (walking speed) and accuracy of the search team members was set to 1, assuming best case properties for the search forces. On the initiation of the attack by the hostile elements, the boarding party followed predetermined way-points to conduct the search and neutralization of hostile elements. Once contact was made with the hostile crew, the boarding team agents took into consideration the cover available and move to the next way-point at a reduced rate.

Hostile Elements: 'Red' hostile agents were equipped with assault rifles with a 30 round capacity and additional 30-round reload. The movement rate of hostile elements was assumed to be slower (1 km/h), as the hostiles were presumed to apply suppression rather than an advance to corner and defeat the boarding and searching elements. Accuracy was set to 80% and body armor was excluded, meaning that hostile elements could be neutralized in one shot. Hostile agent movement settings were configured for preference for cover and concealment from the boarding team and were less inclined to engage the boarding team directly. Hostile agents were also set to attempt ambush positions.

Measures of Effectiveness: to assess the performance of the force and equipment configurations for the red and blue forces, the following MOEs were determined and measured from MANA over 30 runs:

a) Mean boarding team casualties per run

b) Mean hostile crew casualties per run

c) Mean time of run to decisive end

c. Results/Analysis

Table 49 shows an overall summary of the combat model results.

Table 49: Summary of Combat Model Results

Combat Model Results (Sample of 30 runs)	Mean Boarding Team Casualties (out of 10)	Mean Hostile Crew Casualties	# of Blue Wins (out of 30)	# or Red Wins (out of 30)	Mean Time to Decisive End
Container Ship, Initially Subdued	2.3/10	10/10	30	0	95.8 seconds
Cargo Dhow, Initially Subdued	2.1/4	6/6	30	0	14.4 seconds
Container Ship, Initially Hostile	5.6/10	9.0/10	19	11	11 minutes
Cargo Dhow, Initially Hostile	2.5/4	5.3/6	19	11	62.3 seconds

i) Initially Subdued:

a) TEU Container Ship: All 30 runs completed with a decisive ending resulting with a boarding team victory. Mean boarding team casualties stood at 2.30+/-0.09 persons. Mean hostile crew casualties stood at 10.00+/-0.00. The mean time taken to reach a decisive end by the boarding team was 95.8+/-1.6 seconds (1.59 min +/- 1.6 seconds).

b) Cargo Dhow: All 30 runs completed with a decisive ending resulting with boarding team victory. Mean Boarding Team Casualties were recorded at 2.13+/-0.06. Mean Hostile Crew Casualties were 6.00+/-0.00.

Mean time to a decisive end was recorded at 14.4 +/-1.2 (0.24 min +/- 1.2 seconds).

An interesting observation was that both scenarios end under two minutes, suggesting that a subdued crew at the early onset of the boarding led to a potentially short conflict should one arise, irrespective of the size of the ship. Early exertion of control on the ship could have played a role in this.

ii) Initially Hostile:

a) TEU Container Ship: Mean casualties taken by the boarding party are 5.63 +/-0.45. Of 30 runs, the boarding team was the victor in 19 of them. Mean Hostile Crew Casualties were 9.00+/-0.34 at 11 wins. The mean time taken to end each conflict was 704.5+/-102.7 seconds (11mins +/- 2.11mins).

b) Cargo Dhow: 30 of 30 runs completed. Mean Boarding team casualties stood at 2.50+/-0.24. Mean hostile crew casualty numbers were 5.33+/-0.19. The mean time to a decisive win was 62.3+/-2.5 (1.03+/-2.5 seconds).

Intuitively, one expects the larger ship to have a more extended conflict than the smaller cargo dhow. This is so in the MANA simulations. Combat on the Container Ship with the current configurations and performance were shown to result in approximately 50% casualties in the boarding group of 10 personnel. This is the same for the smaller ship, which had fewer hiding places and small deck space to fight within.

d. Further Study

Increasing Ship Complexity: The formulation of a generalized model for the combat simulation was not considered as it was assumed that the general layout of a container ship would reasonably be the same for all standard

TEU carrying ships. It would therefore be interesting to determine if the impact of ship complexity on the outcome of combat situation. This model would evaluate the performance of the boarding party in general situations and its potential performance if the party was expected to board a ship other than a cargo vessel.

Combat Evolving out of Search Underway: For methodical purposes, the combat situations derived either occur spontaneously due to an agitator or are already part of the initial situation. It is reasonable to expect that search inspectors may be attacked during a search. In considering this situation, two questions arose:

- Would it be better if the inspectors adopted a clear-secure-inspect approach to moving from compartment to compartment, or enforced a complete clear, secure and continuous search of the ship? In the event of a combat situation arising, which of these options would perform better?
- Would the involvement of forward sensors have improved the process and the favorable outcome of a combat situation? UGVs and man-operated sensors have been employed desert and urban terrain. Would they have been any impact with respect to a combat situation on a ship?

APPENDIX A. TASKING LETTER

NAVAL
POSTGRADUATE
SCHOOL

10 Oct, 2007

MEMORANDUM FOR SEA-13 STUDENTS

Subj: SEA-13 CAPSTONE PROJECT OBJECTIVES

Enclosures: Tab A: Background for Capstone Project Development
Tab B: Preliminary objectives for the Maritime Interdiction in logistically barren area project

1. The objective of this memorandum is to provide guidance for the conduct of the integrated project which is required as partial fulfillment for your degree. You will deliver your completed project report and final briefing materials to the Project Advisor on or before 30 May 2008, in accordance with the following plan and milestones.

    a. Develop a project proposal and a project management plan during the Fall Quarter 2007. This proposal and plan will serve to focus your initial research and analysis. You should plan to review and update this plan frequently as you progress with your research.
    b. Conduct project reviews approximately every six weeks, finishing with a final brief to be scheduled for the first week of June 2008.
    c. Begin outlining and preparing your Project Report as early as you can. Work with your faculty advisors, about every week, to prepare your Project Report for their approval and signature by 30 May 2008. The edited and processed final report is due on 10 June 2008.

2. The preliminary objectives statement for the project is contained in Tab A. Background information on the character and objectives of the projects is outlined in Tab B. Your initial efforts should be to refine these objectives statements, based on research of current guidance documents and subject to the approval of your faculty advisors.

3. You will be expected to identify and integrate students and faculty from across the campus -- and other resources from outside the school -- to participate directly in your project or to provide source documents, technical knowledge and insights, and knowledge of evolving requirements, capabilities, and systems. This participation could include students who would join your groups, students doing related individual thesis topics such as those from TDSI, faculty inside or outside NPS who have expertise related to your project, and appropriately engaged government agencies and industry developers. Current NPS research projects that have relevance to your project include COASTS, TNT, and Hastily Formed

Networks. It will be your responsibility to integrate the efforts of outside participants in your projects. Your faculty advisors will, of course, assist in these efforts.

4. You should employ the systems engineering and analytical methodology you have been learning in your class work and from your advisors. Your role in the campus-wide integrated project is that of the lead project systems engineering team. In this role you will complete the Project Concepts Exploration phase. This will require you to do a Stakeholder Analysis and Needs Analysis to determine operational requirements for the system which will solve the problem the stakeholders have defined. You will have to define the functions and performances of your system. In executing these tasks you will be defining and understanding the overall project requirements (recognizing that this definition process is iterative and will evolve as the project progresses).

5. You will have to define the selected concepts for supporting systems (the components in your systems) and partition the overall system requirements to be addressed by supporting teams of students and faculty. Your role will include providing central guidance and requirements clarification and resolution, working with supporting teams, and completing your tasks according to your schedule. Ultimately, you will be responsible for integrating the work of supporting teams with your own to form a coherent, cohesive, finished report of the overall project

6. Background research of the references listed in Tab A are only a beginning. You should also become familiar with related past SEA projects such as the Sea Base, Joint Expeditionary Logistics, Riverine, Riverine Sustainment, and Maritime Security and other analytical studies concerning theater security and shaping activities from RAND, IDA, CNA and other institutions and civilian industry.

7. The grades assigned to the participants in these projects will be pass/fail, and will be assigned by the lead faculty advisor. Although you will work as part of a team, your individual performance will be the basis for this evaluation. Successful completion and documentation of your project is a degree requirement.

8. I request each SEA-13 member acknowledge that you have read this letter by signing it and returning it to Professor Langford. (golangfo@nps.edu)

__________ Acknowledged

Wayne P. Hughes Jr.

Wayne Hughes
Chairman
Systems Engineering and Analysis Curriculum Committee
Naval Postgraduate School
Monterey, California

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Tab A

Extended Maritime Interdiction Operations Objectives

Design a system of systems to employ a regional Maritime Interdiction operation in a logistically barren area. The system should be capable of collecting maritime intelligence and conducting rapid intercepts based on that intelligence to execute theater security, crisis response, and law enforcement missions in a coalition, interagency, and joint environment. Consider current fleet structure and funded programs as the baseline system of systems to execute security and shaping missions in developing these concept of operations, then develop alternative architectures for platforms, manning, command and control, communication, and operational procedures to evaluate against the current program.

Tab B

Background for Capstone Project Development

Objective

- Provide educational content appropriate to future professional careers as senior leaders.
- Apply course content to execution of projects.

Character of Capstone Projects

- Address future security environments.
- Relate strategic objectives, systems concepts, operational concepts, and technologies.
- Tailor topics to group size and composition.

Guidelines for SEA-13 Capstone Project Development

- Establish theater specific needs and mission area analysis from Combatant Commander engagement, threat and diplomacy goals.
- Working together, the SEA-13 students will derive threat types and levels.
- Consider your Maritime Interdiction Operation (MIO) system to be capable of employing and supporting coalition, interagency, and joint forces.
- Develop other faculty and student roles for the cross campus integrated projects

Sources of guidance on current national maritime objectives

- NSPD-41/HSPD-11 "Maritime Security Policy"
- National Strategy for Maritime Security
- National Plans for Maritime Security

Related CNO guidance

- Navy Strategic Plan
- CNO Guidance for 2006 POM
- Naval Operational Concept

APPENDIX B. SYSTEMS ENGINEERING INFORMATION

A. DOMAIN PROCESS MODEL DESCRIPTION

The DPM is formulated for problem solving, but in its abstraction, focuses on prototyping trade studies to reach ahead to solutions that then become the drivers for more detailed analyses. The essential domains are requirements, behaviors, architecture, and validation/verification. The dynamics of the Domain Process Model and the operational process is defined by the Behavioral Rules. These Behavioral Rules describe the interconnections among the Enterprise Activities (organic in a logistically barren environment) according to the following paradigms: start and end of a process; or join and iteration. To guarantee consistency among the Enterprise Activities and the functional entities derived from the functional decomposition, a set of capabilities that fulfill the Enterprise activity requirements are specified by scenarios (or UML). Within each domain the analysis proceeds as follows:

1. Requirement interactions

A requirement (from the requirements' domain) interacts with the Behavior Domain, which in turn interacts with the Architecture Domain, which is likewise interactive with the V&V Domain. This interaction takes place in the Process Domain, the harbinger of analyses and trade-offs.

2. Requirement derivations

The requirements are derived as normal in the Systems Engineering Process, representing the customer's view(s) of the system or system of systems. The primary means for deriving requirements is through Functional Analysis (mainstay being functional decomposition and synthesis).

3. Requirement and behaviors

Each requirement is facilitated by a behavior (captured in the Behavior Domain). Behaviors are typically the result of UML (Universal Modeling Language) Activity diagrams (called Workflow Activity Diagrams) that represent the structural and functional enterprise objects. For example, the operations such as enterprise operations (organic), human resources, and equipment resources are captured in workflow concepts using “use cases”. Dropping the formality of UML, and retaining the notion of Workflow Activity Diagrams within Scenarios, suffices sufficiently to map requirements to behaviors.

4. Requirement and architecture

The Behavior Domain interacts with the Architecture Domain by allocating behaviors to physical components. The results of that allocation are considered by trade-studies and recorded in the Process Domain.

Each trade-study and modeling activity is verified and validated in the V&V Domain with inputs from the Requirements Domain and the Architecture Domain.

The ultimate application of the DPM is to derive modules of functionality (activities and processes) that are independent of each other. A module implements an indivisible function, having only one input and one output. Independence means that the function of the module is unaffected by the source of the input, the destination of its output, and the history of the module. Modules must be separately testable and have uniform work content. Such refinements are the signs of a robust process and design. Looking over the application of DPM to SEA-13 implies that modules of work should offer flexibility in changing the aggregate unit to improve performance (and therefore quality). This flexibility is enhanced by dividing the tasks up into major functionalities. The result is a change made to one module should have only local effects for each change to that module of work.

B. FUNCTIONAL DECOMPOSITION OF 'TO DO A MIO'

1.0 Provide Logistic Support
- 1.1 To Transport
  - 1.1.1 Communicate with US TRANSCOM
  - 1.1.2 Establish requirements for supplies at critical nodes
  - 1.1.3 Establish requirements for movement of supplies between nodes and point of departure.
  - 1.1.4 Establish requirements between nodes and resupply areas
  - 1.1.5 Establish nodes
  - 1.1.6 Establish resupply areas
  - 1.1.7 Determine point of departure.
  - 1.1.8 Monitor logistics
    - 1.1.8.1 Analyze equipment availability
    - 1.1.8.2 Monitor levels at nodes
    - 1.1.8.3 Monitor levels at resupply areas
  - 1.1.9 Determine equipment availability
  - 1.1.10 Coordinate sustenance operations
  - 1.1.11 Activate reserve assets
- 1.2 To Maintain
  - 1.2.1 Conduct corrective maintenance
  - 1.2.2 Conduct preventative maintenance
  - 1.2.3 Track numbers and frequencies of failures
  - 1.2.4 Obtain external assistance
    - 1.2.4.1 Ability to reach-back to OEM
    - 1.2.4.2 Ability to reach-back to higher level depot expertise
  - 1.2.5 Send irresolvable defects to higher level depot.
- 1.3 To Supply
  - 1.3.1 Provide material services
  - 1.3.2 Design
  - 1.3.3 Procurement
  - 1.3.4 Contracting
  - 1.3.5 Receive supplies
  - 1.3.6 Store supplies
  - 1.3.7 Inventory control
  - 1.3.8 Issuance
  - 1.3.9 Retrograde Supplies
  - 1.3.10 Disposal of end items (repairables and consumables)

2.0 Provide for Information Superiority
- 2.1 Conduct Communications
  - 2.1.1 Select appropriate equipment
    - 2.1.1.1 Determine worst-case ranges
    - 2.1.1.2 Determine worst-case environmental conditions
    - 2.1.1.3 Determine worst-case data-rate needs

2.1.1.4 Match channel impediments and requirements with comms equipment capabilities
2.1.2 Acquire comms equipment
2.1.3 Disperse comms equipment to operating personnel
2.1.4 Perform training on operation of communications gear

2.2 Do Intelligence work
2.2.1 Plan Information Collection
2.2.1.1 Plan for biometric collection
2.2.1.2 Determine need for document exploitation
2.2.1.3 Determine need for non-networked computer exploitation (NNCE)
2.2.2 Collect Information
2.2.2.1 Maintain a chain of custody of intelligence
2.2.2.2 Collect Biometric Information
2.2.2.2.1 Take face pictures
2.2.2.2.2 Take fingerprints
2.2.2.2.3 Take Iris photographs
2.2.2.3 Collect document information
2.2.2.3.1 Create digital images of documents
2.2.2.3.2 Search for documents
2.2.2.4 Collect information from non-networked computers (NNC)
2.2.2.4.1 Gain physical access to NNC
2.2.2.4.2 Copy computer hard-drives
2.2.2.4.3 Search computer hard-drives
2.2.2.4.4 Offload gathered data
2.2.3 Process and Explain information
2.2.3.1 Move information
2.2.3.1.1 Move collected information from target ship to parent ship
2.2.3.1.1.1 Electronically transmit information
2.2.3.1.1.1.1 Render information into transmittable form
2.2.3.1.1.1.2 Encrypt information at Target ship
2.2.3.1.1.1.3 Transmit information from Target ship to parent ship
2.2.3.1.1.1.4 Receive information at parent ship
2.2.3.1.1.1.5 Decrypt information at parent ship
2.2.3.1.1.1.6 Verify success of transmission at parent and target ship
2.2.3.1.1.2 Physically move information

2.2.3.1.1.2.1 Package information for safe handling
2.2.3.1.1.2.2 Apply appropriate markings
2.2.3.1.1.2.3 Identify route to physically move captured information
2.2.3.1.1.2.4 Identify information carrier
2.2.3.1.1.2.5 Move information
2.2.3.1.1.2.6 Unpackage information
2.2.3.1.2 Move collected information from parent ship to off ship subject matter expert (SME)
2.2.3.1.2.1 Identify route to SME
2.2.3.1.2.2 Encrypt Information
2.2.3.1.2.3 Transmit from parent ship to SME via identified route.
2.2.3.1.2.4 Receive information at SME
2.2.3.1.2.5 Decrypt information
2.2.3.1.2.6 Verify success of transmission
2.2.3.2 Translate captured documents to Parent ship native language
2.2.3.3 Receive information from SMEs
2.2.4 Analyze Information
2.2.5 Disseminate Information
3.0 Manage Operations
3.1 Determine force requirements/mix
3.2 Determine Mission
3.3 Contingency planning
3.3.1 Handle confiscated ship disposal
3.3.2 Handle disposal of toxic/elicit cargo
3.4 Assign parent ships to target ships
3.5 Maintain a common operational picture
3.5.1 Determine friendly force status
3.5.1.1 Communicate with friendly forces
3.5.1.2 Receive position/status reports from friendly units
3.5.2 Achieve Maritime Domain Awareness
3.6 Disperse orders to friendly forces
4.0 Maneuver
4.1 Receive mission/orders
4.2 Launch UAV for ISR
4.3 Intercept compliant adversaries (level 1)
4.3.1 Close to within VHF radio range
4.3.2 Instruct target vessel via bridge to bridge radio, channel 16.
4.3.3 Observe vessel response
4.3.4 Position parent ship for ideal employment of boarding team
4.3.5 Launch boarding teams

4.3.6 Support boarding teams
4.3.7 Recover boarding teams

4.4 Intercept non-compliant adversaries (levels 2 and 3)

4.4.1 Launch armed UAV or armed manned helicopter
4.4.2 Launch armed USV
4.4.3 Utilize Rules of Engagement
4.4.4 Demonstrate a show of force
4.4.5 Fire warning shots
4.4.6 Employ non-violent weapons
4.4.7 Implement disabling fire
4.4.8 Conduct battle damage assessment

4.4.8.1 Determine if boarding is now level 1

4.5 Intercept hostile adversaries (level 4)

4.5.1 Same procedures as 4.4.

4.6 Protect the boarding team

4.6.1 Provide armed presence in vicinity of boarding team
4.6.2 Utilize rules of engagement
4.6.3 Conduct ISR in vicinity of boarding team
4.6.4 Communicate with the boarding team
4.6.5 Respond to calls for fire from the boarding team

5.0 To Board

5.1 Assemble boarding teams [8 member teams]

5.1.1 Receive/process/disseminate information/intelligence on vessel to be boarded.

5.1.1.1 Determine classification of the ship
5.1.1.2 Determine compliant status
5.1.1.3 Determine non-compliant status
5.1.1.4 Determine opposed status

5.1.2 Determine equipment for boarding based on ship's status
5.1.3 Conduct boarding brief on methods and procedures to use to board the target vessel.

5.1.3.1 Determine insertion/extraction method

5.1.3.1.1 Prepare for air insertion/extraction
5.1.3.1.2 Prepare for sea insertion/extraction

5.1.3.2 Conduct communications

5.1.3.2.1 Conduct pre-emptive communications check
5.1.3.2.2 Conduct communications between team members
5.1.3.2.3 Conduct communications between teams and parent ship.

5.2 Launch boarding teams (Sea/Air)

5.2.1 Launch scout team(s)

5.2.1.1 Conduct initial check of vessel (SH-60/UAV/Scout team)
5.2.1.2 Confirm the vessel is safe to board

5.2.1.3 Approach and board vessel

5.3 Board Vessel (Approx 8 member team)

5.3.1 Board sweep team for initial security investigation (2 members)

5.3.1.1 Provide initial check of ship for personnel/suspicious activity.

5.3.2 Board engineering team (2 members)

5.3.2.1 Consult with target ship's main engineer

5.3.2.2 Inspect target ship's engineering spaces

5.3.3 Board Security team (1-2 members)

5.3.3.1 Muster the crew on the forecastle

5.3.4 Board boarding officer & assistant boarding officer

6.0 Search

6.1 Determine search methodology (exhaustive, random or targeted)

6.2 Determine search target set (weapons, narcotics, people, etc)

6.3 Determine needed asset mix to search a ship

6.3.1 Determine number of people needed

6.3.2 Determine amount of time needed

6.3.3 Determine a probability of detection

6.3.4 Determine a probability of false alarm

6.4 Transport search equipment to or from the parent and target ships.

6.5 Search the ship

6.5.1 Unpack containers

6.5.2 Repack containers

6.5.3 Search inside containers

6.5.4 Conduct swabs for IMS analysis

6.5.5 Conduct IMS analysis

6.5.6 Utilize search equipment

7.0 Recover

7.1 Utilize armed assets to provide security for boarding team

7.1.1 Communicate with supporting assets

7.1.2 Transmit status to supporting assets

7.1.3 Receive warnings from supporting assets

7.2 Disembark from target ship

7.3 Return to parent ship

8.0 Detain

8.1 Communicate with detained ship

8.2 Determine weapons availability

8.3 Match weapons to target

8.4 Determine weapons payload

8.5 Utilize show of force against detained ship

8.6 Utilize warning shots against detained ship

8.7 Utilize disabling fire against detained ship

8.8 Conduct BDA against detained ship

8.9 Utilize non-lethal weapons against detained ship

9.0 Destroy

9.1 Determine weapons availability
9.2 Match weapons to target
9.3 Determine weapons payload
9.4 Determine CEP for intended weapon
9.5 Assess battle damage
9.6 Report event

10.0 Legal
- 10.1 Develop Rules of Engagement
- 10.2 Communicate intelligence into evidence
- 10.3 Determine status of displaced persons
- 10.4 Extradite captured personnel to host-nations
- 10.5 Ensure detainee rights upheld
- 10.6

11.0 Abort
- 11.1 Determine threat scenario
- 11.2 Determine needs for additional assets
- 11.3 Determine time to withdraw
- 11.4 Launch additional ISR assets
- 11.5 Launch additional fire support assets
- 11.6 Launch SAR assets
- 11.7 Launch additional RHIBs or helicopters for PAX transfer
- 11.8 Integrate new assets into command and control scheme
- 11.9 Retrieve search equipment/team (expeditiously)
- 11.10 Retrieve boarding team (expeditiously)

APPENDIX C. CONCEPT OF OPERATIONS

A. SITUATION

1. General

a. Environment

Global Shipping lanes are vital to the new Global Economy. Despite recent advances in transportation and aircraft, ships still remain the cheapest way to move large amounts cargo, a long distance. The maritime environment provides a route for neutral, friendly, and enemy forces to move cargo, material, and people in the busy shipping lanes. As a part of the continuing war on terror, Maritime Intercept and Security operations are a growing set of capabilities required to protect United States flagged vessels and maintain the ocean free for international trade. The loss of the sea lanes would be catastrophic to the United States and her Allies. The goals of the operations are hard to define but critical to protect; therefore operations may be terminated upon reaching a political environment conducive to ending operations.

b. Policy Goals

Military conditions leading to mission accomplishment are impossible to verify. Worthy goals such as the elimination of terrorism, smuggling, or piracy are impossible to measure. However, goals such as the achievement of theater security may be measured modestly through the observation of free flow of maritime trade in the AO and through a measurable reduction in incidents of piracy and maritime terrorism.

c. Non-US National Political Decisions

Since shipping lanes are global by nature, the U.S. government and NGOs should be ready to cooperate and facilitate operations to support free trade in the maritime environment. The U.S. is committed to U.N. Conference on the Law of The Sea (UNCLOS) even pending ratification by the Senate. This document provides guidelines to nations on the enforcement of sovereignty in the maritime environment, and the commitment to have fee use of the seas for the purpose of trade.

d. Operational Limitations

Operations shall be limited by the U.N. Conference on the Law of the Sea, including but not limited to international convention regarding territorial waters and international straits. Although the United States has not formally ratified this document it abides by the principles of the document.

The Area of Operations is assumed to be logistically barren, which means all items are available but their expected arrival time and lifetime is not known. Therefore, the force must be self-sustaining for a period of at least 90 days. The force must also be capable of conducting robust search operations and the Visit Board and Search aspects of the MIO mission. U.S. forces must also be capable of protecting U.S. flagged vessels and U.S. territory in the region.

2. Area of Concern

a. Operational Area

The Battle Space is defined as any Littoral or Open Ocean area in the World. The U.S. and coalition will establish Maritime Security Zones with international cooperation to protect all shipping and interdict all disruptive cargo in the operating area.

b. Area of Interest

The force shall be concerned with any high interest shipping lanes, defined by high density traffic of a multi-national nature and a frequent recurrence of piracy. The force shall also monitor critical choke points in its AO due to the significance these passages hold to the global economy and a global interest in keeping these straits open to traffic. The force must also be capable of searching a large area for specific targets for intercept.

3. Deterrent Operations

The force will be capable of conducting deterrent operations at any time during the operations. These operations will include the escort of U.S. flagged vessels the enforcement of the UNCLOS principles, and defense of U.S. EEZ and sovereign waters.

4. Risk

Risk to friendly units includes loss of life and equipment, infringement on sovereign nations' territorial waters, and impedance of Maritime trade (via boarding operations).

5. Adversary Forces

Adversary forces are not traditional state-based military organizations. The adversaries belong to three distinct groups: Disruptive, pirate, and smuggler.

a. Adversary Centers of Gravity

Disruptive organizations use merchant traffic to achieve their political goals. The maritime shipping lanes are their center of gravity.

Pirates target merchant traffic for the purpose of financial profit. They require a home base from which to conduct raids on shipping. The pirates' center of gravity is the coastal home village.

Smugglers exploit the sea lanes to move their various goods for financial profit. The smugglers' center of gravity is the maritime shipping lanes.

For purposes of these CONOPS the focus will be Disruptive organizations.

(1) Strategic

State-sponsored camps/ governments

State or Non-State Sponsored Military Camps

(2) Operational

Cargo Vessels

Military/ Para-military units

b. Adversary Courses of Action

(1) General:

The enemy will spread its ideals to regional states to achieve a governments aligned with their ideals. The will use any means to transport illegal cargo across the maritime domain. They will not hesitate to attack neutral and adversary forces to achieve their endstate.

(2) Adversary's End State:

The formation of a group of disruptive states with the same ideology in the region is the political and economic goal.

(3) Adversary's Strategic Objectives:

To prevent U.S. and Allied Nations use of the shipping lanes without acknowledging the disruptive state as regional power.

(4) Adversary's Operational Objectives:

Deny use of Global straits to the global economy.

(5) Adversary's Concept of Operations:

Utilize the busy straits to move equipment and personnel within the region to achieve regional goals. Disrupt the straits using any means while protecting shipments and enemy supplies incoming to the home island.

c. Other Adversary Forces and Capabilities

Coalition forces can expect enemy shipping up to 300 tons with weapons up to 50 cal and RPG. The enemy will also use large commercial ships but will not protect the cargo; instead it will rely on the volume of traffic to disguise its true intent. The enemy may resort to hidden explosive and suicide attacks to achieve its goals.

d. Adversary Reserve Mobilization

None, the enemy has mobilized to its full extent.

6. Friendly Forces

a. Friendly Centers of Gravity

(1) Strategic:

The disruption / destruction of U.S. flagged cargo vessels through the straits. Also the disruption / destruction of goods destined to or from U.S. ports

b. Multinational Forces

Due to the global nature of international channels and shipping lanes the U.S. expects to work with a coalition force. Regional allies, regional support agencies, or countries with similar economic interests would all be potential force contributors. The protection of global straits will also receive attention from the United Nations and other international governing bodies.

c. Supporting Commands and Agencies

The Commander would expect significant support from the Department of State in building a coalition and members of the combined force.

7. Assumptions

a. Threat Warning and Timeline

Not Included due to General Nature of these CONOPS

b. Pre-positioning and Regional Access

Regional access is expected from Coalition partners providing forces.

c. In-Place Forces

Within the organic force, various ships will carry different numbers and varieties of MIO Boarding Teams (BTs). The teams shall be VBSS and HVBSS capable. PC/FFG will carry two BTs each, while DDG/CG and LPD/LSD will carry three BTs each. LHD/CVN will carry four BTs. The LPD/LSD/LHD/CVN shall be SOF capable.

d. Strategic Assumptions

Non-organic forces in the AO are expected to be fluid and vary by region. However, it is assumed that UAV/USV/UCAVs are available and that there are Red Cross assets in place in the region.

Because AO is considered logistically barren, there will be no logistic support. Forces must be sustainable for 90 days.

UN support, if any, will be limited.

e. Legal Considerations

(1) International Law and the Law of Armed Conflict, to include the UNCLOS will apply. MIO during Transit Passage and in Littoral Areas must be handled carefully and in accordance with UNCLOS.

(2) United States Law

(3) Host nation and Coalition laws

(4) ROE will be limited. Self Defense always applies.

(5) Status-of-Forces Agreements

(6) Other bilateral treaties and agreements including Article 98 agreements

B. MISSION

1. To deny Disruptive/Criminal/Pirate organizations from moving people, goods, weapons, or supplies through the established Maritime Domain.

2. To keep Sea Lanes open for trade and commerce while denying the enemy the ability to resupply or damage coalition states.

C. EXECUTION

1. Concept of Operations

a. Commander's Intent

(1) Purpose and End State

Operation will be terminated based on conditions of the political environment. When policy goals have been met and the political environment is conducive to ending operations, the Coalition leaders will issue orders to terminate operations.

(2) Objectives

To conduct Maritime Intercept Operations, spanning the continuum of force as required, with zero friendly losses.

Orientation on adversary's strategic and operational COGs.

Protection of friendly strategic and operational COGs.

(3) Effects

Reduction in disruptive/pirate events.

Increase in cooperation from local mariners and governments, such as an increase in reports of suspicious activity and an increase in local law enforcement participation.

b. General

(1) JFC's military objectives, supporting desired effects, and operational focus

(2) Orientation on the adversary's strategic and operational COG's

(3) Protection of friendly strategic and operational COG's

c. PHASE OPERATIONS

Found in Chapter 3

APPENDIX D. INDIVIDUAL PLATFORM RESULTS

(Characteristics used in evaluation were derived from the source: Jane's Fighting ships)

The following are the results and breakdown of the 108 ship platforms based on 10 characteristics. Each characteristic was weighted and then each ship's total score compared as discussed in Chapter V.

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
Tarawa class (LHA)	0.26	1.15	1.15	0.72	0.38	1.15	1.03	0.90	1.15	1.15	9.05
LHA 6 class	0.26	1.15	1.15	0.62	0.45	1.15	1.03	0.90	1.15	1.15	9.01
Wasp class (LHD)	0.26	1.15	1.15	0.62	0.38	1.15	1.03	0.90	1.15	1.15	8.95
Ticonderoga class cruisers (US)	0.51	1.04	1.04	0.82	0.51	1.04	0.92	0.81	1.15	1.04	8.88
Arleigh Burke class (US)	0.51	1.04	1.04	0.82	0.51	1.04	0.92	0.81	1.15	1.04	8.88
Keelung (Kidd) class (Taiwan)	0.58	1.04	1.04	0.92	0.51	1.04	0.72	0.81	1.15	1.04	8.85
Spruance class (US)	0.51	1.04	1.04	0.82	0.45	1.04	0.92	0.81	1.15	1.04	8.82
San Antonio class LPD (US)	0.26	1.15	1.15	0.62	0.38	1.15	0.82	0.90	1.15	1.15	8.74
Austin class LPD (US)	0.26	1.15	1.15	0.62	0.38	1.15	0.82	0.72	1.15	1.15	8.56
De la Penne (Italy)	0.51	1.04	1.04	0.82	0.45	1.04	0.72	0.72	1.15	1.04	8.53
Hobart Class (Australia)	0.51	0.92	0.92	0.82	0.51	1.04	0.72	0.81	1.15	1.04	8.45
Jeanne de Arc (France)	0.45	1.04	1.15	0.82	0.38	0.81	1.03	0.54	1.15	1.04	8.41
Cheng Kung class (KWANG HUA 1 PROJECT) (Taiwan)	0.45	1.04	0.92	0.82	0.45	0.81	0.92	0.81	1.15	1.04	8.41
Alvaro de Bazan (Spain)	0.51	0.92	0.92	0.82	0.45	1.04	0.72	0.81	1.15	1.04	8.38
Muavenet (Knox) (Turkey)	0.51	0.92	0.92	0.82	0.45	1.04	0.72	0.81	1.15	1.04	8.38

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
Freedom class (LCS)	0.45	0.35	0.92	1.03	0.51	1.04	0.92	0.81	1.15	1.15	8.33
Elli (Kortenaer) class (Greece)	0.45	0.81	0.92	0.82	0.45	1.04	0.92	0.72	1.15	1.04	8.32
Oliver Hazard Perry Class (Australia)	0.45	0.92	0.92	0.82	0.45	0.81	0.92	0.81	1.15	1.04	8.29
Oliver Hazard Perry class (US)	0.45	0.92	0.92	0.82	0.45	0.81	0.92	0.81	1.15	1.04	8.29
G-Class (OH Perry) (Turkey)	0.45	0.92	0.92	0.82	0.45	0.81	0.92	0.81	1.15	1.04	8.29
Anzac Class (Australia)	0.51	0.81	0.92	0.82	0.45	1.04	0.72	0.81	1.15	1.04	8.27
Iroquois (Canada)	0.45	0.92	1.04	0.82	0.51	1.04	0.82	0.45	1.15	1.04	8.24
Barbaros class (MEKO 200TN type) (Turkey)	0.51	0.81	0.92	0.82	0.51	1.04	0.72	0.72	1.15	1.04	8.24
ENDURANCE CLASS (Singapore)	0.38	1.04	1.15	0.41	0.38	1.15	0.92	0.72	1.04	1.04	8.24
Maestrale (Italy)	0.45	0.92	0.92	0.82	0.45	1.04	0.72	0.72	1.15	1.04	8.23
Hydra class (Meko 200 HN) (Greece)	0.51	0.81	0.92	0.72	0.45	1.04	0.72	0.81	1.15	1.04	8.17
Whidbey Island/Harpers Ferry (LSD)	0.26	1.15	1.15	0.62	0.38	1.15	0.41	0.72	1.15	1.15	8.15
Santa Maria (Spain)	0.45	0.92	0.92	0.82	0.45	0.81	0.72	0.81	1.15	1.04	8.09
Broadsword class Type 22 (UK)	0.45	0.92	1.15	0.82	0.45	0.81	0.72	0.54	1.15	1.04	8.05
Bremen (Germany)	0.51	0.92	1.04	0.82	0.45	0.81	0.72	0.54	1.15	1.04	8.00
AHMAD YANI (VAN SPEIJK) CLASS (FFGHM)	0.38	0.92	0.92	0.72	0.45	1.04	0.72	0.63	1.15	1.04	7.97
Daring class Type 45 (UK)	0.38	0.81	0.92	0.72	0.45	1.04	0.92	0.54	1.15	1.04	7.97
Type 42 (UK)	0.45	0.92	1.04	0.82	0.45	0.81	0.72	0.54	1.15	1.04	7.94
Cassard (France)	0.45	0.92	1.04	0.82	0.45	0.81	0.72	0.54	1.15	1.04	7.94

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
Kang Ding (La Fayette) class (Kwang Hua 2 project) (Taiwan)	0.45	0.81	0.92	0.62	0.38	1.04	0.72	0.81	1.15	1.04	7.94
Halifax (Canada)	0.38	0.92	0.92	0.82	0.45	1.04	0.72	0.45	1.15	1.04	7.90
La Fayette (France)	0.45	0.81	0.92	0.72	0.38	1.04	0.72	0.63	1.15	1.04	7.86
GEARING (WU CHIN III CONVERSION) (FRAM I) CLASS (Taiwan)	0.51	0.92	0.92	0.82	0.26	1.04	0.72	0.45	1.15	1.04	7.83
MULTIROLE VESSELS (LPD/APCR)	0.26	0.92	1.04	0.31	0.32	1.04	0.92	0.81	1.15	1.04	7.81
FATAHILLAH CLASS (FFG/FFGH)	0.45	0.81	0.58	0.82	0.45	1.04	0.72	0.72	1.15	1.04	7.77
Duke class Type 23 (UK)	0.45	0.81	0.92	0.82	0.45	0.81	0.72	0.54	1.15	1.04	7.71
Vasco da Gama (Portugal)	0.38	0.69	0.58	0.62	0.45	1.04	0.92	0.54	1.15	1.04	7.41
Thetis class (Denmark)	0.45	0.46	1.04	0.51	0.45	1.04	0.72	0.54	1.15	1.04	7.40
FORMIDABLE CLASS (Singapore)	0.45	0.46	0.81	0.82	0.45	0.81	0.72	0.81	1.04	1.04	7.40
Baleares (Spain)	0.51	0.92	1.04	0.82	0.32	1.04	0.41	0.00	1.15	1.04	7.26
Baptista de Andrade (Portugal)	0.38	0.69	0.58	0.62	0.45	1.04	0.72	0.54	1.15	1.04	7.21
KAKAP (PB 57) CLASS (NAV III and IV) (LARGE PATROL CRAFT) (PBOH)	0.32	0.69	0.58	0.82	0.45	0.81	0.72	0.63	1.15	1.04	7.21
Yavuz (MEKO 200 type) (Turkey)	0.51	0.81	0.92	0.82	0.45	0.00	0.72	0.72	1.15	1.04	7.14

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
Tariq (Amazon) (Pakistan)	0.51	0.81	0.92	0.82	0.51	1.04	0.63	0.69	1.15	0.00	7.09
Horizon (France)	0.51	0.81	0.92	0.82	0.45	0.00	0.72	0.54	1.15	1.04	6.96
STEREGUSHCHIY CLASS (PROJECT 20382) (FFGH)	0.45	0.00	0.92	0.72	0.38	0.81	0.72	0.72	1.15	1.04	6.91
Georges Leygues (France)	0.45	0.81	0.92	0.82	0.45	1.04	0.72	0.54	1.15	0.00	6.90
Knox class (Taiwan)	0.45	1.04	0.92	0.72	0.32	0.81	0.00	0.45	1.15	1.04	6.90
Tourville (France)	0.45	0.92	1.04	0.82	0.38	0.81	0.72	0.54	1.15	0.00	6.83
Zulfiquar (Leander) (Pakistan)	0.38	0.92	0.92	0.72	0.45	0.81	0.63	0.69	1.15	0.00	6.68
Joao Coutinho (Portugal)	0.45	0.46	0.46	0.62	0.45	0.81	0.41	0.54	1.15	1.04	6.38
KI HAJAR DEWANTARA CLASS (FFGH/FFT)	0.45	0.81	0.92	0.51	0.38	0.81	0.72	0.63	0.00	1.04	6.27
Braunschweig (Germany)	0.45	0.46	0.00	0.62	0.38	0.81	0.72	0.54	1.15	1.04	6.17
TACOMA TYPE (LSTH)	0.32	0.92	1.04	0.31	0.38	1.04	0.92	0.81	0.00	0.00	5.74
Floreal (France)	0.45	0.46	0.35	0.62	0.38	0.81	0.72	0.63	1.15	0.00	5.56
Artigliere (Italy)	0.32	0.81	0.92	0.92	0.45	1.04	0.00	0.00	0.00	1.04	5.50
Joao Belo (Portugal)	0.38	0.81	0.92	0.62	0.38	1.04	0.00	0.00	0.00	1.04	5.19
Descubierta (Spain)	0.45	0.69	0.81	0.72	0.38	1.04	0.00	0.00	0.00	1.04	5.13
SAMADIKUN (CLAUD JONES) CLASS (FF)	0.38	0.92	0.92	0.41	0.38	1.04	0.00	0.00	0.00	1.04	5.10
River PC (UK)	0.38	0.12	0.35	0.51	0.38	1.04	0.00	0.00	1.15	1.04	4.97
Suffren (France)	0.45	1.04	1.04	0.82	0.38	1.04	0.00	0.00	0.00	0.00	4.77
Minerva (Italy)	0.32	0.69	0.58	0.62	0.45	1.04	0.00	0.00	0.00	1.04	4.73

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
Pyrpolitis (Hellenic 56) class (Batch 1) (Greece)	0.45	0.35	0.92	0.72	0.38	0.81	0.00	0.00	0.00	1.04	4.67
Armatolos (Osprey 55) class (Greece)	0.45	0.35	0.92	0.72	0.38	0.81	0.00	0.00	0.00	1.04	4.67
Ho Hsing class (LARGE PATROL CRAFT) (Taiwan)	0.19	0.69	0.58	0.62	0.51	1.04	0.00	0.00	0.00	1.04	4.67
SIGMA CLASS (CORVETTES) (FS)	0.38	0.81	0.58	0.72	0.38	0.81	0.72	0.00	0.00	0.00	4.40
KAPITAN PATIMURA (PARCHIM I) CLASS (PROJECT 1331) (FS)	0.38	0.69	0.58	0.51	0.38	0.81	0.00	0.00	0.00	1.04	4.40
Jin Chiang class (LARGE PATROL CRAFT) (Taiwan)	0.38	0.58	0.58	0.62	0.38	0.81	0.00	0.00	0.00	1.04	4.38
Laskos (La Combattante III) class (Greece)	0.51	0.35	0.35	0.82	0.45	0.81	0.00	0.00	0.00	1.04	4.32
Offshore patrol vessel (Taiwan)	0.26	0.35	0.58	0.62	0.38	1.04	0.00	0.00	0.00	1.04	4.26
Offshore patrol craft (Taiwan)	0.19	0.35	0.58	0.82	0.45	0.81	0.00	0.00	0.00	1.04	4.23
Niels Juel class (Denmark)	0.45	0.46	0.35	0.72	0.38	0.81	0.00	0.00	0.00	1.04	4.21
TODAK (PB 57) CLASS (NAV V) (LARGE PATROL CRAFT) (PBO)(Indonesia)	0.32	0.46	0.58	0.62	0.38	0.81	0.00	0.00	0.00	1.04	4.21
SINGA (PB 57) CLASS (NAV I and II) (LARGE PATROL CRAFT) (PBO)	0.38	0.35	0.58	0.72	0.32	0.81	0.00	0.00	0.00	1.04	4.19

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
Coastal patrol craft (Taiwan)	0.19	0.46	0.58	0.72	0.38	0.81	0.00	0.00	0.00	1.04	4.18
Machitis class (Greece)	0.38	0.35	0.35	0.72	0.38	0.92	0.00	0.00	0.00	1.04	4.14
VICTORY CLASS (Singapore)	0.45	0.35	0.00	0.92	0.51	0.81	0.00	0.00	0.00	1.04	4.08
Hunt PC (UK)	0.38	0.12	0.35	0.51	0.38	0.00	0.00	0.00	1.15	1.04	3.94
PULAU RENGAT (TRIPARTITE) CLASS (MHSC)	0.26	0.46	0.58	0.31	0.45	0.81	0.00	0.00	0.00	1.04	3.90
Yun Hsing class (COASTAL PATROL CRAFT) (Taiwan)	0.19	0.46	0.58	0.51	0.26	0.81	0.00	0.00	0.00	1.04	3.85
DAMEN STAN PATROL 3507 (PATROL CRAFT) (Singapore)	0.26	0.23	0.00	0.92	0.51	0.81	0.00	0.00	0.00	1.04	3.77
Niki (Thetis) (Type 420) class (Greece)	0.38	0.35	0.35	0.51	0.32	0.81	0.00	0.00	0.00	1.04	3.76
KAL-36 PATROL CRAFT (PB)	0.26	0.23	0.00	0.92	0.45	0.81	0.00	0.00	0.00	1.04	3.71
Kilic (Turkey)	0.45	0.35	0.58	0.92	0.38	0.81	0.00	0.00	0.00	0.00	3.49
FEARLESS CLASS (Singapore)	0.45	0.23	0.00	0.51	0.45	0.81	0.00	0.00	0.00	1.04	3.49
Tolmi (asheville) class (Greece)	0.45	0.23	0.00	0.62	0.26	0.81	0.00	0.00	0.00	1.04	3.40
Pao Hsing class (COASTAL PATROL CRAFT) (Taiwan)	0.19	0.35	0.00	0.51	0.32	0.81	0.00	0.00	0.00	1.04	3.22
D'Estienne D'Orves (Turkey)	0.38	0.69	0.58	0.72	0.38	0.00	0.00	0.00	0.00	0.00	2.76

Ship class	Organic Arms	Crew size	# of teams	Speed	# of eng/ size	# of small boats	# of helos	Helo Type	UAV Cap	USV Cap	Total score
DAGGER CLASS (FAST ATTACK CRAFT-MISSILE) (PTFG)	0.45	0.46	0.58	0.82	0.45	0.00	0.00	0.00	0.00	0.00	2.76
Yildiz class (FPB 57 type)(Turkey)	0.45	0.35	0.58	0.92	0.38	0.00	0.00	0.00	0.00	0.00	2.68
Azmat (Huangfeng/Osa-I) (Pakistan)	0.32	0.35	0.69	0.92	0.38	0.00	0.00	0.00	0.00	0.00	2.67
Votsis (La Combattante IIA) (Type 148) class (Greece)	0.45	0.35	0.35	0.92	0.45	0.00	0.00	0.00	0.00	0.00	2.51
Roussen (Super Vita) class (Greece)	0.45	0.35	0.35	0.82	0.51	0.00	0.00	0.00	0.00	0.00	2.47
Larkana (Pakistan)	0.32	0.35	0.69	0.62	0.32	0.00	0.00	0.00	0.00	0.00	2.29
Jalalat (Pakistan)	0.26	0.35	0.69	0.62	0.32	0.00	0.00	0.00	0.00	0.00	2.23
AUK CLASS (Philippines)	0.32	0.46	0.69	0.41	0.32	0.00	0.00	0.00	0.00	0.00	2.21
SEA WOLF CLASS (FAST ATTACK CRAFT-MISSILE) (Singapore)	0.38	0.35	0.00	0.92	0.51	0.00	0.00	0.00	0.00	0.00	2.17
Rajshahi (Town class) (Pakistan)	0.26	0.23	0.69	0.62	0.26	0.00	0.00	0.00	0.00	0.00	2.05
TOMAS BATILO (SEA DOLPHIN) CLASS (FAST ATTACK CRAFT) (Philippines)	0.26	0.23	0.00	0.92	0.38	0.00	0.00	0.00	0.00	0.00	1.79
CYCLONE CLASS (COASTAL PATROL SHIP) (Philippines)	0.13	0.23	0.00	0.92	0.38	0.00	0.00	0.00	0.00	0.00	1.67
SAN JUAN CLASS (Philippines)	0.00	0.23	0.00	0.62	0.45	0.00	0.00	0.00	0.00	0.00	1.29

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APPENDIX E. RESULTS FOR OPTIMIZATION OF FORCE STRUCTURE BASED ON MANPOWER

Appendix E shows the results of the Excel solver breakdown of ships to form the force structure to be compared with the three baseline Expeditionary Strike Groups with manpower being held constant. The results displayed are from an imposed 10 ship constraint as well as an unconstrained version to show feasibility as discussed in Chapter V.

Qty	Ship class	Total Manpower	Performance
1	Type 42- Batch Destroyer	599	7.94
1	Muavenet (Knox)	250	8.38
1	San Antonio class	720	8.74
1	Spruance class ASW/strike destroyers	350	8.82
2	Keelung (Kidd) class (DDGHM)	726	17.69
2	Ticonderoga class cruisers	774	17.77
2	Arleigh Burke class large multirole destroyers	724	17.77
10	Max people	**4143**	

	Max performance		**87.12**
Constraint:	Total # of ships	Max ships deployable	
	10	**10**	

Force Package 1:	Total Manpower	Performance
1x LHA, 1x Ticonderoga CG, 1x DDG, 1x LSD, 1x LPD, 1x FFG	4143	86.39
Force Package 2:		
1x LHD, 1x LPD, 1x LSD, 1x FFG, 2x DDG	4218	86.22
Force Package 3:		
1x LHD, 1x LPD, 1x LSD, 1x FFG, 1x DDG	3856	85.69

Unconstrained:

75

Joao Coutinho (2), Machitis class(2), Laskos (La Combattante III)(2), Niki (Thetis) (Type 420)(2), Pyrpolitis (Hellenic 56)(2), Armatolos (Osprey 55) (2), Votsis (La Combattante IIA) (2), Tolmi (asheville) (2), Freedom class (LCS)(2), Kilic (2), Azmat(2), Larkana (2), Rajshahi (2), River PC(2), Hunt PC (2), Jin Chiang (2), Offshore patrol vessel (2), Offshore patrol craft (2), Coastal patrol craft (1), Pao Hsing (2), Braunschweig (2),

APPENDIX F. RESULTS FOR OPTIMIZATION OF FORCE STRUCTURE BASED ON THE # OF HELICOPTERS.

Appendix F shows the results of the Excel solver breakdown of ships to form the force structure to be compared with the three baseline Expeditionary Strike Groups with the number of helicopters being held constant. The results displayed are from an imposed 10 ship constraint as well as an unconstrained version to show feasibility as discussed in Chapter V.

QTY	Ship Class			Maximum Helos	Maximum Performance
1	Arleigh Burke class			2	8.88
1	Type 45- Daring Destroyer			1	7.97
2	AHMAD YANI (VAN SPEIJK) CLASS (FFGHM)			2	15.95
2	Ticonderoga class cruisers			4	17.77
2	Keelung (Kidd) class (DDGHM)			2	17.69
2	Jeanne de Arc			18	16.82
			Total	**29**	
			Total		**85.09**
Constraint:	Total # of ships	Max ships deployable			
	10	**10**			
Force Package 1:					
1x LHA, 1x Ticonderoga CG, 1x DDG, 1x LSD, 1x LPD, 1x FFG				**31**	**86.39**
Force Package 2:					
1x LHD, 1x LPD, 1x LSD, 1x FFG, 2x DDG				**31**	**86.22**

Force Package 3:		
1x LHD, 1x LPD, 1x LSD, 1x FFG, 1x DDG	**29**	**85.69**
Unconstrained:		
31	**31**	**82.2**

2 Alvaro de Bazan, 2 Santa Maria, 2 Hobart, 2 Anzac, 2 Hydra, 2 Austin, 2 Whidbey Island, 2 Muavenet (Knox), 2 Barbaros (Meko 200), 2 Type 22 Broadsword, 2 Type 42 Batch, 2 Type 45 Daring, 2 Cassard, 2 Keelung (Kidd), 1 Kang Ding, 2 Ahmad Yani

APPENDIX G. RESULTS FOR OPTIMIZATION OF FORCE STRUCTURE BASED ON THE # OF RIGID HULL INFLATABLE BOATS

Appendix G shows the results of the Excel solver breakdown of ships to form the force structure to be compared with the three baseline Expeditionary Strike Groups with the number of RHIBs being held constant. The results displayed are from an imposed 10 ship constraint as well as an unconstrained version to show feasibility as discussed in Chapter V.

QTY	Ship Class		Maximum # of RHIB's	Maximum Performance
1	Keelung (Kidd) class (DDGHM)		2	8.85
1	G-Class (OH Perry)		1	8.29
2	Cheng Kung class (KWANG HUA 1 PROJECT) (FFGHM)		2	16.82
2	Arleigh Burke class		4	17.77
2	Ticonderoga class		4	17.77
2	Jeanne de Arc		2	16.82
		Total	**15**	
		Total		**86.32**

Constraint:

Number of ships	Max ships deployable
10	**10**

Force Package 1:		
1x LHA, 1x Ticonderoga CG, 1x DDG, 1x LSD, 1x LPD, 1x FFG	**17**	**86.39**
Force Package 2:		
1x LHD, 1x LPD, 1x LSD, 1x FFG, 2x DDG	**17**	**86.22**

Force Package 3:			
1x LHD, 1x LPD, 1x LSD, 1x FFG, 1x DDG		**15**	**85.69**
Unconstrained:			
17	1 Type 42 Batch, 2 Cassard, 2 Bremen, 2 Cheng Kung, 2 G-class (OHP), 2 Jeanne de Arc, 2 FFGs, 2 Santa Maria, 2 Type 22 Broadsword	**17**	**81.7**

APPENDIX H. IBIS MOBILE IDENTIFICATION SYSTEM

Appendix H is a summary of L-1 Identity Solution's IBIS Mobile Identification System. It details a summary of the equipment's functions, performance and system requirements, and specifications. Its use is further discussed in Chapter VII.

L-1 IDENTITY SOLUTIONS
IDENTIX BIOMETRIC SOLUTIONS

IBIS Mobile Identification System

Over Tens of Thousands of Field Searches

Proven Deployments

"During the last six months, our officers identified over 800 subjects using mobile identification technology. One hundred and twelve (112) of those subjects were arrested for giving false information to a police officer or for outstanding warrants. A recent arrest involved a reputed hardcore gang member that had approximately $2.6 million dollars in outstanding warrants and was considered 'armed and dangerous'. This subject actually bragged about giving false information to law enforcement officers in other jurisdictions. Without mobile identification technology, this subject would still be walking the streets endangering our community."

Lieut. Jeffrey A. Rose
San Bernardino County
Sheriff's Department
CAL-ID Division

The Integrated Biometric Identification Systems (IBIS) have a long history of success, beginning with our patent combining fingerprints and photos with wireless connections[1]. Since then, hundreds of mobile units have been deployed with demonstrated time and cost savings through cite outs and remote bookings, increased arrests, and solved crimes. We continue to develop award-winning products by incorporating technologically advanced designs to better serve our customers.

Our newest IBIS solution employs a modular handheld device that links via Bluetooth to any pre-configured, supported PDA, taking advantage of today's latest smart-phone technology. A card reader module to scan documentation, such as a driver's license, and the workflow manager can interface with various databases simultaneously, including our AFIS system. This flexibility, combined with the forensic quality fingerprint reader, the camera on the PDA, and autocapture capability, ensure more accurate IDs and significant time and cost savings for officers in the field.

[1]Patent 5,222,152

MORE ACCURATE ID's

- Captures photographs and forensic quality fingerprint images for AFIS searches in industry standard NIST EFTS format
- Interoperates with a variety of databases (AFIS, WIN, MAFIN, IDENT, NCIC, warrant files, gang files, mug shot systems, etc.)
- Does not rely on name and DOB searches or any verbal information provided by the subject

SIGNIFICANT TIME/ COST SAVINGS

- Delivers real-time ID information for on-the-spot decision making
- Helps prevent false arrests or releases
- Avoids logistical and spatial challenges of integrating expensive and bulky cradles in police cruisers

FLEXIBILITY TO MEET YOUR SPECIFIC NEEDS

- Utilizes the latest wireless communications (EVDO and EDGE)
- Works with any PDA using Windows® Mobile 2005
- Leverages your existing cellular service to avoid redundant fees

IBIS Mobile Identification Process

IBIS Mobile Identification System Specifications

Fingerprint Sensor	
Platen Dimensions	1.3" Vertical x .9" Horizontal
Image Dimensions	1.0" Vertical x .8" Horizontal (500x400 Pixels)
Geometric Distortion	1.5% or less
Illumination Uniformity	3db or less at the edges and corners; Non-uniformity piecewise monotonic throughout
Resolution	500dpi +/- 2%
Grayscale Quantization	8 bits per pixel
Magnetic Strip Card Reader	
Tracks	3 Track
Format	ANSI/ISO/CDL/AAMVA standards
2-D Bar Code Reader	
Format	PDF 417 and 2-D matrix bar codes
Operating Conditions	
Temperature, Operating	32 to 104 F (0 to 40 C)
Temperature, Non-Operating	4 to 120 F (-20 to 50 C)
Operating Humidity	10% - 90%
Mechanical Dimensions	9.7" L x 2.6" W x 2.5" D (hood extends above body by 0.75")
Mechanical Weight	0.99 lb (15.8 oz)
Power	
External Connectors	12 VDC power for charging batteries
Battery	NiMH rechargeable 1.5 VDC, 4 each All battery life shown is for NiMH rechargeable (May also use standard 1.5 VDC AA Cell, non-rechargeable)
Operating Life	Over 500 two-finger bookings per full battery charge
Life (Standby)	Up to seven (7) days
PDA Requirements	Windows Mobile 2005 32 Mbytes RAM 64 Mbytes Flash
Supported Cellular Technologies	EVDO/CDMA 1XRTT (Sprint/Verizon) EDGE/GPRS (Cingular)
Other	RoHS Compliant

L-1 IDENTITY SOLUTIONS
IDENTIX BIOMETRIC SOLUTIONS

Award-Winning Technology

2007
CTIA Emerging Technology Award

2004
Government Computing News Award

2003
Qualcomm CDMA-List Award

2003
Minnesota Tekne Award

5705 W. Old Shakopee Rd, Suite 100
Bloomington, MN 55437
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www.L1id.com

APPENDIX I. HAND-HELD INTERAGENCY IDENTITY DETECTION EQUIPMENT

Appendix I is a summary of L-1 Identity Solution's Hand-Held Interagency Detection Equipment. It gives a detailed summary of the equipment and its functions. It also shows the system specifications and requirements needed to operate this equipment. Its use is discussed in Chapter VII.

L-1 IDENTITY SOLUTIONS

HIIDE™ Series 4

Hand-Held Interagency Identity Detection Equipment

Industry First Portable Multi-modal Enrollment and Recognition Device

HIIDE™ Features and Benefits

- High-Capacity Storage
  Each HIIDE™ can store up to 10,000 full biometric portfolios. One portfolio contains 2 iris templates, 10 fingerprints and a facial image
- Untethered Ability
  Identify a subject in stand-alone mode without the restraint of being tethered to a host PC.
- Expandable
  Customize the HIIDE™ by adding USB-enabled peripheral devices including live-scan devices, passport or card readers, or an external keyboard and mouse.

The HIIDE™ device is the most powerful tool ever developed for biometric identification. Users can enroll, match or verify with the three primary biometrics; iris, finger and face. The intuitive user interface also allows the entry of biographic data to create a comprehensive database on the enrolled subjects.

The HIIDE has an onboard processor and data storage capacity and is the only device that allows complete functionality while connected to a host PC or when operating in the field untethered.

Small, rugged and lightweight, the HIIDE™ is a critical component in the worldwide need for faster more accurate identity solutions.

How It Works

The HIIDE™ is a Microsoft XP embedded device that includes state-of-the art lens technology for both iris and facial image capture and an FBI standards compliant 500 DPI capacitive fingerprint sensor.

Enrollment on the HIIDE™ is accomplished through an easy-to-use step-by-step wizard process starting off with capturing a subjects left and right iris images. The HIIDE™ can then capture all ten fingerprints and finally a facial image is acquired. The user can choose to skip any or all of the biometric captures for maximum flexibility. Once the biometric capture is completed, the user can input a fully customizable biographic information file and save the enrollment.

Recognition of a subject can be performed using either the iris or fingerprint biometric for 1:N searches or a 1:1 verification using facial recognition.

SecuriMetrics Incorporated
An L-1 Identity Solutions Company

L-1 IDENTITY SOLUTIONS

Layering Biometrics

The world of biometrics has moved from solutions involving single biometric modalities to ones of increasing complexity such as national identification projects. These projects often involve two or three biometric modalities.

HIIDE™ utilizes the speed and accuracy of iris identification, the ability to access large fingerprint databases, and the social acceptance that comes with facial recognition. Combined in a single device, this offers a powerful tool that can be customized to fit almost any identification scenario.

HIIDE™ Series 4 Specifications

Item	Description	Comment
Physical	Height	5 inches (127 mm)
Dimensions	Width	8 inches (203 mm)
	Depth	3 inches (76 mm)
	Weight	2 lbs 3 oz. (1361 grams)
Hardware	CPU	AMD 533 MHz, 16K Instruction, 16K Data Cache
	Display	640 x 480 Color Touch-Screen LCD
	Memory – RAM	256 MB
	Compact Flash Socket	Up to 4 GB supported
	Battery	Dual 2000 mAh (Total 4000mAh) Hot Swappable, Lithium
Ion	Connectivity	10/100BaseT PCI Ethernet, 2 x USB ports
Image Capture	Iris Capture Camera	640 X 480 (VGA) monochrome Focal distance – 8 - 10" Capture Rate – 15fps (Approximately)
	Face Capture Camera	640 X 480 (VGA) color Focal distance – Approximately 36" Capture Rate – 15fps Approximately
	Fingerprint Sensor	Capacitive 500dpi, Capture Rate – 14fps
Illuminators	Infrared Illumination	Dual Band IR:(Safety tested)
Accessories	Power Supply + Power cord	For charging HIIDE™ device
	Deluxe Hard & Soft Case	For storage of the HIIDE™ device
	External Battery Charger	
	Additional Battery, Stylus	
Capacity	10,000 template portfolio capacity +1,000 image based portfolio capacity	Fingerprint, face and iris templates + biographical info

"We believe that the use of biometrics, specifically iris recognition, in the War on Terror could help prevent another 9/11 from happening. SecuriMetrics' handheld device allows flexibility of use on the battlefield and provides a level of accuracy we have not seen before with biometrics. If the use of these devices can save just one life, we will have received benefit from our investment. Our goal is to use them to save many lives and win the War on Terror"

Lieutenant Colonel Kathy DeBolt

US Army Battle Laboratory

Fort Huachuca, Arizona

SecuriMetrics Incorporated

An L-1 Identity Solutions Company

757 Arnold Drive, Suite D
Martinez, CA 94553
Telephone 925-229-2212
Facsimile 925-228-6568

www.L1id.com

APPENDIX J. ROBOTIC SAILBOAT

As described in chapter seven, one candidate system for consideration in a system to conduct large area maritime surveillance was the robotic sailboat. Specifications for that craft are below.

AUSV PRODUCTION VESSEL

Production Open-Ocean AUSV and Baseline Sensor Array

- Length (hull): 45’ 0” overall
- Beam (hulls): 45’ 0” overall
- Mast height: 60’ 0”
- Communication to command center by satellite links
- Draft: (hydrofoils lowered): 10’
- Payload: 1-3,000 lbs.
- Stowage capacity: 600 cu. ft.
- Airfoil surface: 600 sq. ft.
- Foil-borne speed: 30+ knots
- Range: 500+ mi. aux. power
- Time at sea: 3+ months

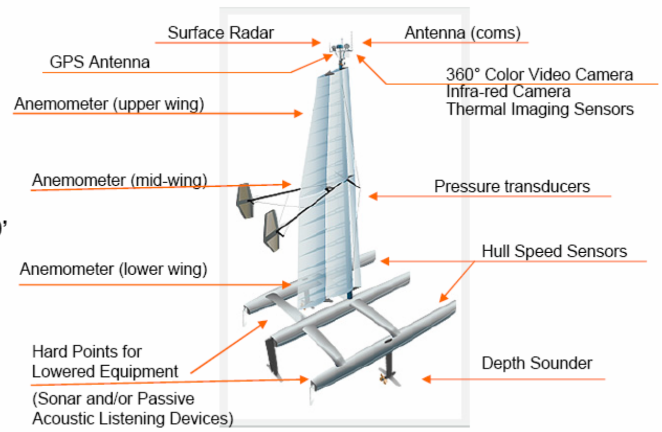

Figure 78: Autonomous Unmanned Surface Vehicle (AUSV) Characteristics

AUSV COST ADVANTAGE

- AUSV unit cost
  - Open-ocean vessel - $2.8 million
  - Coastal vessel - $2.2 million
  - Cost in 2007 dollars with baseline sensor suite
  - Can support advanced sensor/communication capability with Navy furnished equipment
- Significant life-cycle savings vice conventional ships, helicopters or aircraft
  - No crew, no fuel
  - Cheaper to acquire, operate and maintain
  - Frees scarce platforms for more critical missions

Figure 79: Marketing Information from Harborwing Technoligies, Inc.

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APPENDIX K. SELECTION FOR THE UAV

A. SELECTION PROCESS FOR THE UAV

1. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) was used to evaluate the three suitable UAV candidates (A160 Hummingbird, MQ-8B Fire Scout and Seamos) and select the best platform based on the evaluating criteria.

The evaluating criteria used in AHP analysis are external payload (weight), endurance, capabilities (existing + projected), interoperability, ease of integration and program risk. The weights of the criteria are provided below and were based on the priority of mission success.

a. External Payload (weight – 13.6%).

The requirement for external payload is not less than 100kg. The higher the payload the platform can carry will be given a higher score.

b. Endurance (weight – 11.4%).

The requirement for endurance is not less than 3 hours. The platform with the higher endurance will be given higher score.

c. Capabilities (weight – 17.6%).

The UAV should have surveillance, identification, force protection, targeting and precision attacked capabilities. The platform with the larger roles will be given a higher score. In some cases, the UAV might not be equipped with the required capabilities but there are programs on-going to integrate the capabilities on the UAV. Special consideration will be given for these cases.

d. Interoperability (weight – 18.0%)

Interoperability is a critical consideration in the integration of the platform on the surface ship. If the level of interoperability is high, the platform can utilize the existing facilities of the ship to operate and maintain the platform.

e. Ease of Integration (weight – 19.1%)

Ease of integration is usually the main consideration when integrating an outside platform on the surface ship. The new platform will have its own dedicated control station, special equipment and maintenance requirements and the ease of integrating these systems will decide the score for this criteria.

f. Program Risk (weight – 20.3%)

Program risk would involve many factors such as the ability to meet the schedule, the level of new technology and integration involved, funding and etc.

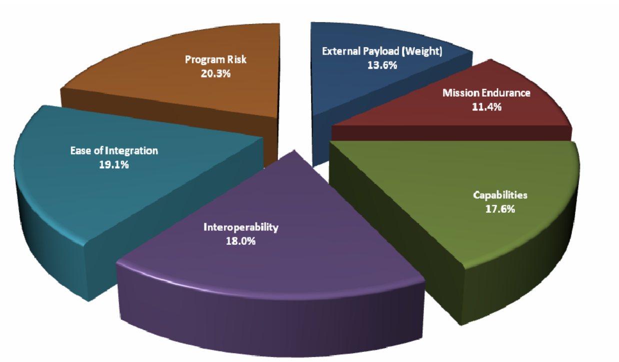

Figure 80: Criteria Weight

The ability of the 3 UAVs in meeting the criteria are tabulated below.

Criteria	Ability to meet Criteria		
	Fire Scout	Hummingbird	Seamos
External Payload	320 kg	136 kg (300 lbs)	150 kg
Endurance	+5 hrs	24-36 hrs	4 hrs
Capabilities			
- Surveillance & Identification	Yes	No	Yes
- Targeting	Yes	No	Yes
- Precision Attack	Planned	No	No
Interoperability	High	High	Medium
Ease of Integration	High	Medium	Medium
Program Risk	Low	High	Medium

Table 50: Criteria for UAV Selection

Based on AHP run, MQ-8B Fire Scout has a global weighted evaluation of 56.7%, A160 Hummingbird of 26.8% and Seamos of 16.5%.

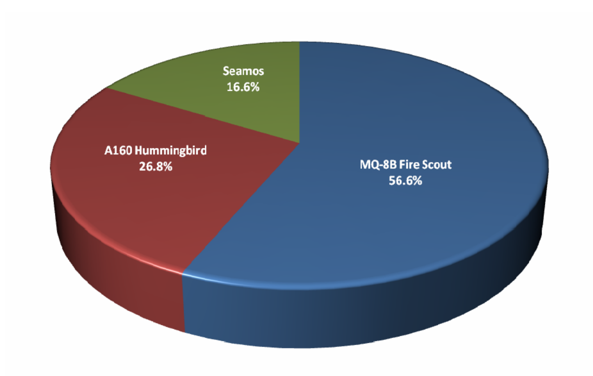

Figure 81: Global Weightage for UAV Selection

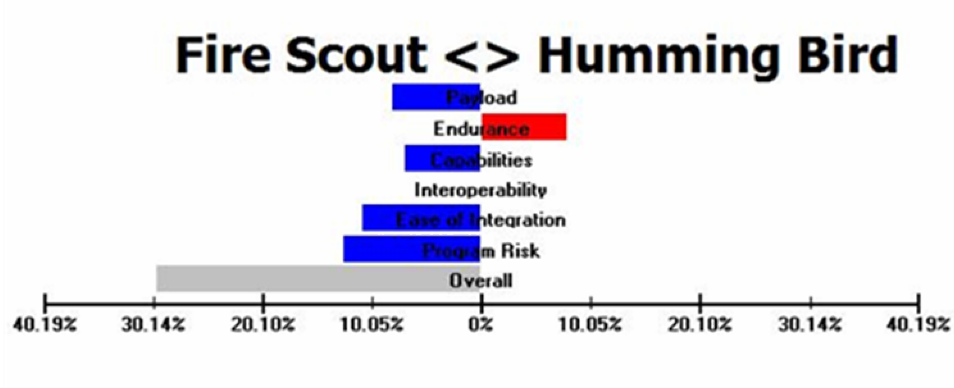

Figure 82: Head to Head Weightage Between Fire Scout and Humming Bird

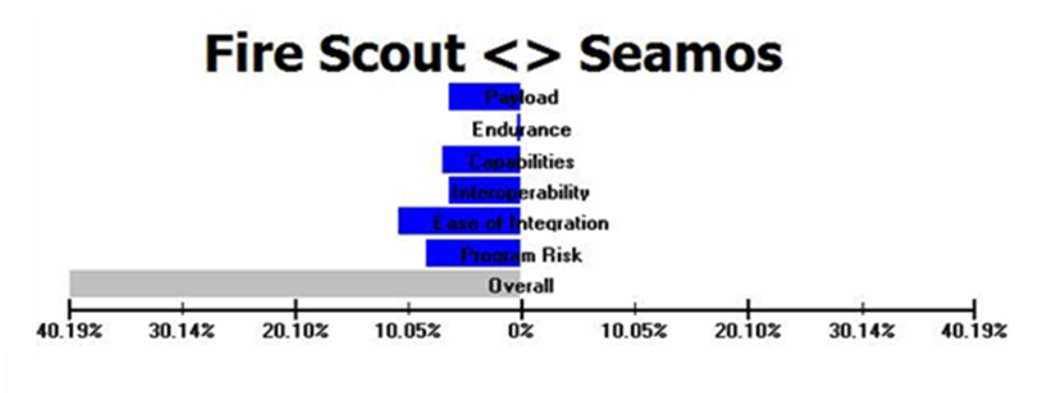

Figure 83: Head to Head Weightage Between Fire Scout and Seamos

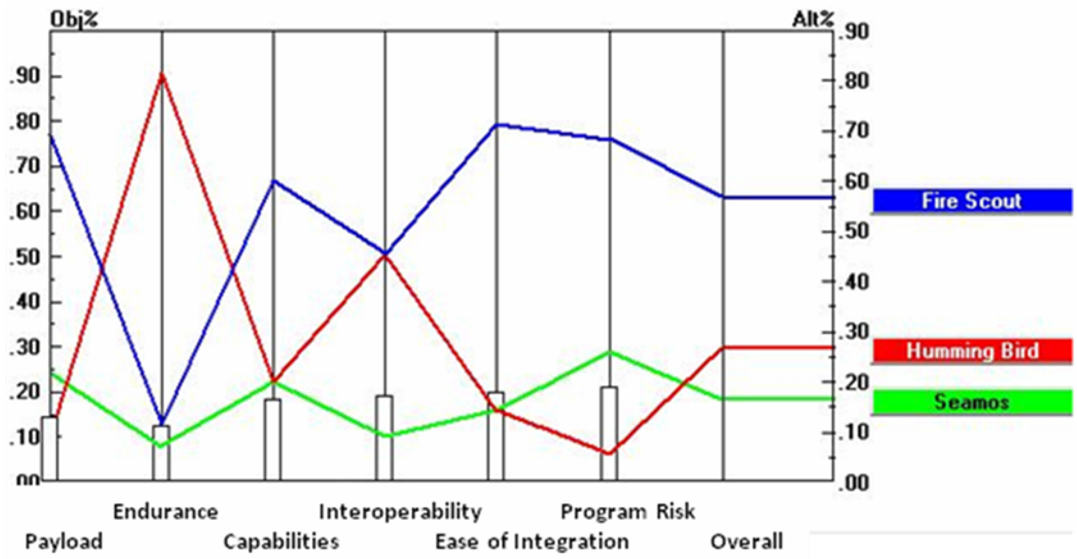

Figure 84: AHP Results for UAV Selection

It is recommended, based on AHP results, to select **Fire Scout (56.7%)** as the Unmanned Aerial Vehicle for MIO mission.

B. TECHNICAL SPECIFICATION

1. Technical Specification for A160 Hummingbird (US)

Figure 85: A160 Humming Bird

Length:	35 feet
Rotor Diameter:	36 feet
Gross Weight:	4,300pounds
Engine:	P&W PW207D Turboshaft
Speed:	140knots
Ceiling:	30,000fts
Total Flight Time:	30 to 40 hrs
Estimated range:	2,500+ nm
Payload:	1,000 lbs
Current Payload:	Nil
Projected Payload:	Unknown
Weapon Payload:	Nil

2. Technical Specification for MQ-8B Fire Scout (US)

Figure 86: MQ-8B Fire Scout

Length Folded: 22.87 ft (7.0 m)

Rotor Diameter: 27.50 ft (8.4 m)

Height: 9.42 ft (2.9 m)

Gross Weight: 3150 lbs (1,428.8 kg)

Engine: Rolls-Royce, Model 250-C20W

Speed: 125+ Knots

Ceiling: 20,000 ft (6.1 km)

Total Flight Time with Baseline Payload: 8+hrs

Total Flight Time with 500 lb Payload: 5+ hrs

Estimated range with Baseline Payload: 110nm

Payload Weight: 320kg

Current Payload: EO/ IR/ LD BRITE Star II, UHF/ VHF Comm relay, COBRA Mine Detector, Airborne Comm Package

Weapon Payload: Hydra Universal Rail launcher with 4 70mm rockets, Viper Strike Munitions (future), Hellfire (future)

Useful Links:

http://www.northropgrumman.com/unmanned/firescout/gallery/index.html#Broch

3. Technical Specification for Seamos (Germany)

Figure 87: Seamos

Length: 2.89m

Height: 2.5m

Gross Weight: >1000kg

Engine: One 450 hps Rolls-Royce 250-C20R Turboshaft

Speed: 90kts (max), 55 to 80kts (cruise)

Ceiling: 12,000ft

Total Flight Time: 4.7hrs

Estimated range: 110nm

Payload: 150kg

Current Payload: Surveillance and target acquisition equipments

Weapon Payload: Nil

Useful Links:

Internet:

http://www.globalsecurity.org/military/world/europe/seamos.htm

Video:

http://www.youtube.com/watch?v=Ag7OVFI9oCU&feature=related

APPENDIX L. SELECTION PROCESS FOR THE USV

Analytic Hierarchy Process (AHP) was used to evaluate the three suitable USV candidates (Protector, Spartan and Silver Marlin) and select the best platform based on the evaluating criteria.

Similar to the criteria used in UAV selection, the evaluating criteria used in the AHP analysis are External Payload (weight), Endurance, Capabilities (existing + projected), Interoperability, Ease of Integration and Program Risk. However, their weights are different from UAV criteria. Again, the weights are selected in terms of mission success priority.

1. External Payload (weight – 18.0%)

The requirement for external payload is not less than 1500lbs. The higher the payload the platform can carry, the higher the assigned score.

2. Endurance (weight – 7.0%)

The requirement for endurance is not less than 10 hours. The platform with the higher endurance will be given a higher score.

3. Capabilities (weight – 15.6%)

The UAV should have surveillance, identification, force protection, targeting and precision attacked capabilities. The platform with the larger roles will be given a higher score. In some cases, the UAV might not be equipped with the required capabilities but there are programs on-going to integrate the capabilities on the UAV. Special consideration will be given for these cases.

4. Interoperability (weight – 18.7%)

Interoperability is a critical consideration in the integration of the platform on the surface ship. If the level of interoperability is high, the platform can utilize the existing facilities of the ship to operate and maintain the platform.

5. Ease of Integration (weight – 18.9%)

Ease of integration is usually the main consideration when integrating an outside platform on the surface ship. The new platform will have its own dedicated control station, special equipment and maintenance requirements. The ease of integrating these systems will decide the score for these criteria.

6. Program Risk (weight – 21.8%)

Program risk would involve many factors such as the ability to meet the schedule, the level of new technology and integration involved, funding and etc.

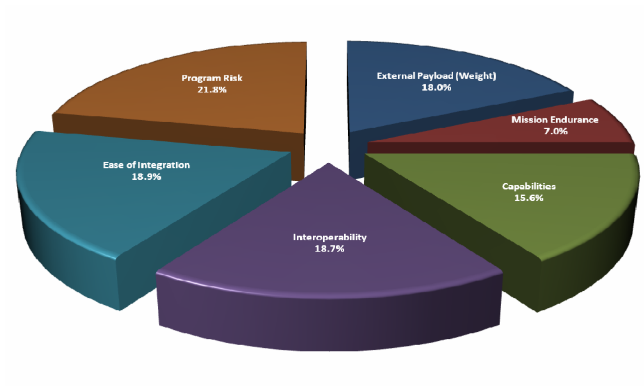

Figure 88: Criteria Weightage for USV Selection

The ability of the 3 USVs in meeting the criteria are tabulated below.

Criteria	Ability to meet Criteria		
	Protector	Spartan	Silver Marlin
External Payload	2,200 lbs	5,000lbs	5,500 lbs
Endurance	Unknown	48 hrs	24 hrs
Capabilities			
- Surveillance & Identification	Yes	Yes	Yes
- Targeting	Yes	Yes	Yes
- Show of Force	Yes	Yes	Yes
- Precision Attack	No	Planned	No
Interoperability	Medium	High	Medium
Ease of Integration	Medium	High	Medium
Program Risk	Medium	Low	Medium

Table 51: Criteria for USV Selection

Based on AHP analysis, the Spartan USV has a global weighted evaluation of 56.9%, Protector at 16.3% and Silver Marlin at 26.8%.

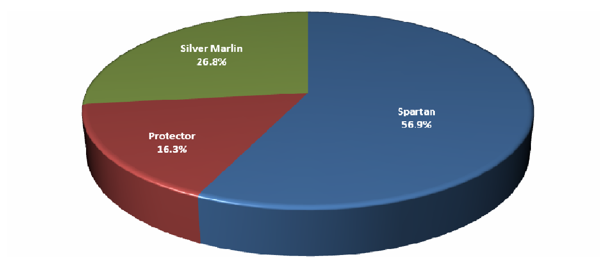

Table 52: Global Weight for USV Selection

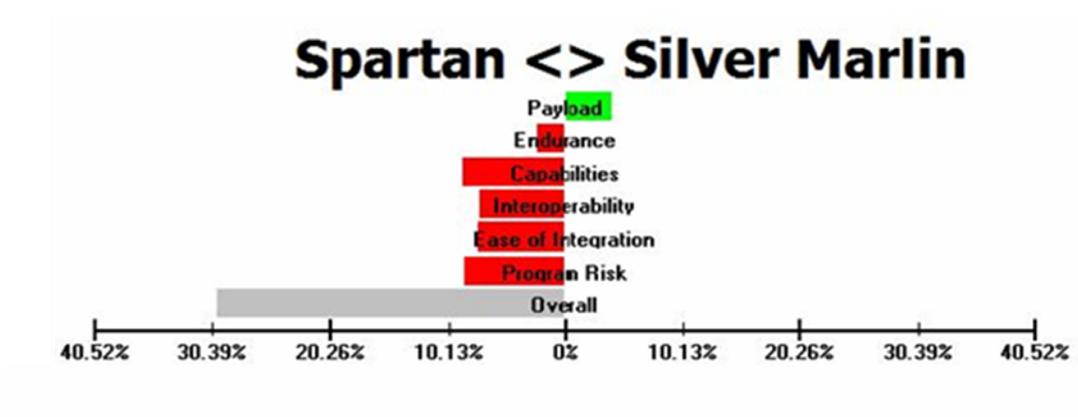

Figure 89: Head to Head Between Spartan and Silver Marlin

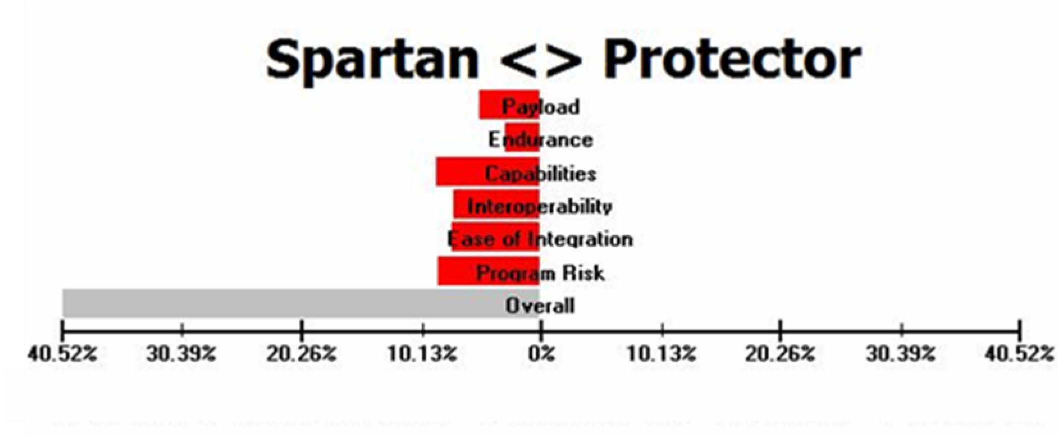

Figure 90: Head to Head Between Spartan and Protector

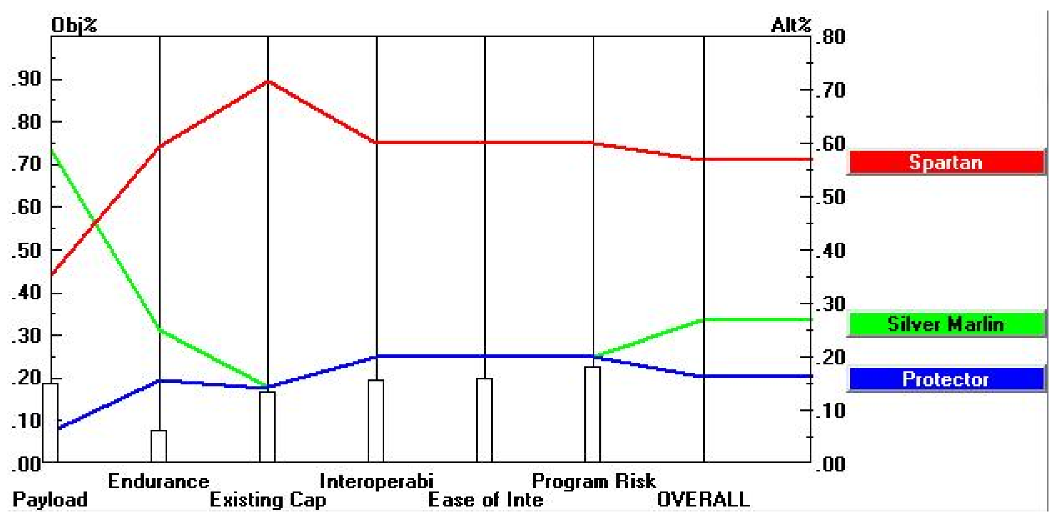

Figure 91: AHP Results for USV Selection

It is recommended, based on AHP results, to select **Spartan (56.9%)** as the Unmanned Surface Vehicle (USV) for MIO mission.

A. TECHNICAL SPECIFICATIONS

1. Technical Specification for Protector (Israel)

Figure 92: Protector

Length: 9 m

Speed: - 30kts

Endurance: unknown

Estimated range: unknown

Payload: 2,200 lbs

Current Payload: EO/FLIR/IR surveillance

Laser Range Finder

Loudspeaker + microphone

Weapon Payload: Mini-Typhoon Machine Gun

Useful Links:

http://www.mindef.gov.sg/imindef/publications/cyberpioneer/3g_saf/2005/features/may05_cs.html

http://www.rafael.co.il/marketing/SIP_STORAGE/FILES/3/633.pdf

2. Technical Specification for Spartan (US)

Figure 93: Spartan

Length: 9 m

Speed: 50 kts

Endurance: 48 hrs

Estimated range: 1,000nm

Payload: 5,000 lbs

Current Payload: EO/FLIR/IR surveillance

Laser Range Finder

Chemical/Biological Detector

Loudspeaker + microphone

Weapon Payload: GAU-17 7.62mm Gun

Hellfire Missiles (projected)

Javelin Missiles (projected)

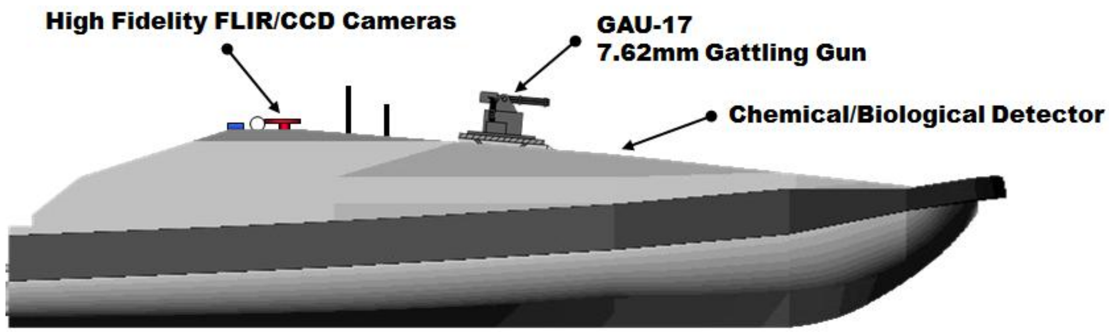

Figure 94: Spartan USV fitted with GAU-17 Gatling Gun (Proposed)

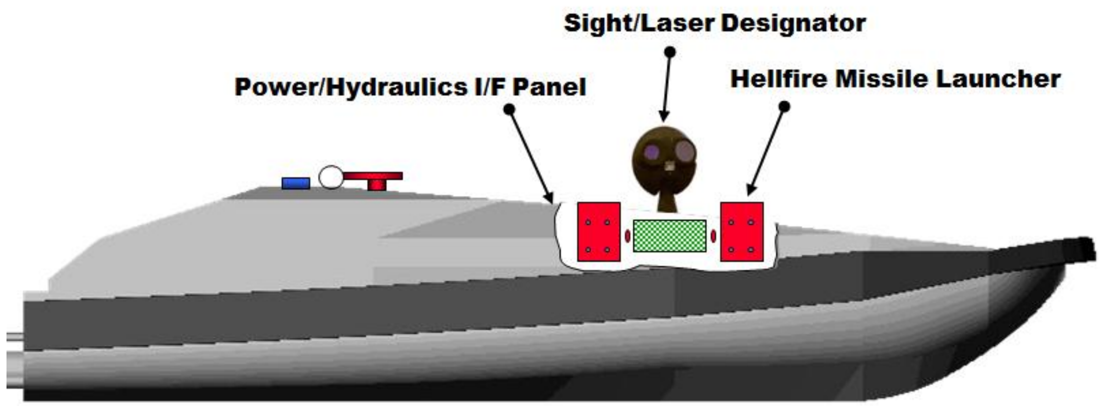

Figure 95: Spartan USV fitted with Hellfire (Proposed)

APPENDIX M. TECHNICAL SPECIFICATIONS OF LETHAL WEAPONS

A. TECHNICAL SPECIFICATIONS OF LETHAL WEAPONS

1. AGM-114M HELLFIRE Missile

Figure 96: AGM-114M Hellfire Missile

Primary Role: Used to engage and destroy naval and urban targets. It is reported to be capable of sinking or disabling a vessel between 500 to 700 tons and is effective against fast attack craft and landing craft.

a. General Characteristics

Diameter	= 7 inches
Length	= 1.63 m
Weight	= 48kg
Effective Range	= 0.5km to over 8km
Max Time-of-Flight (TOF)	= 39s
Unit cost	= US$77K
Propulsion	= Single stage solid propellant
Max speed	= >1.3 Mach

b. Seeker Characteristics

Seeker = Semi-Active Laser Seeker

Mode = LOBL or LOAL

The target is illuminated by a laser designator aimed by a fire-control system/operator. The designator need not to be together with the launcher and can be located several kilometers away in a co-operative mode of operation.

c. Warhead Characteristics

Type- Blast fragment warhead (externally scored steel case designed to break into around 100 even-sized shrapnel fragments supplemented by incendiary pellets)

Weight - 12.5kg

Explosives- PBXN 109 Pyrophoric warhead

Fuse = Impact + delay fuse to detonate after penetration for maximum effects against small frigates.

2. FGM-148 JAVELIN Missile

Figure 97: FGM-148 Javelin Missile

Primary Role: Man-portable medium-range close combat/anti-armor weapon system.

a. General Characteristics

Diameter	= 5 inches
Length	= 1.1 m
Weight	= 49.5lbs (full up system)
Effective Range	= 75m to 2.5km
Max Time-of-Flight (TOF)	= Unknown
Unit cost	= US$80K
Propulsion	= 2 stage solid propellant

b. Seeker Characteristics

Seeker = Infrared Homing

Mode = LOBL

The Javelin is equipped with an imaging infrared seeker which is based on a cadmium mercury telluride (CdHgTe) 64x64 staring focal plane array in the 8 to 12 micron band.

c. Warhead Characteristics

Type = Tandem shaped charge HEAT

Weight = 8.4kg

Precursor warhead to initiate explosive reactive armor and a main warhead to penetrate base armor.

d. Launch System Characteristics

Launch system consists of a Command Launch Unit (CLU) and Launch Tube Assembly (LTA). The CLU has a thermal sight which is used to find, target and fire the missile.

e. Other Characteristics

The soft launch capability of the Javelin allows it to have only a minimal black blast area.

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APPENDIX N. SELECTION PROCESS FOR NON LETHAL WEAPONS

A. SELECTION PROCESS FOR NON LETHAL WEAPONS

Analytic Hierarchy Process (AHP) was used to evaluate the three suitable weapon types, namely: water cannon, remote long range acoustic device (LRAD-R) and mobility denial system (MDS) for deployment on the selected USV platform.

The evaluating criteria used in AHP analysis are ease of integration, equipment operating range, ease of operation, weapon effectiveness and maintainability. The weights of the criteria are provided below.

1. Ease of Integration (weight – 21.7%)

Ease of integration is usually the main consideration when integrating an external weapon/payload on the USV.

2. Effective Operating Range (weight – 27.5%)

The effective operating range of the weapon should allow maximum stand off range between the operating platform and target of interest.

3. Weapon Effectiveness (weight – 37.6%)

Weapon effectiveness compares the “lethality” of the weapon, i.e. the extent in which the effects of the weapon can influence its target.

4. Weapon Maintainability (weight – 8.5%)

Consider the ease of maintaining the weapon system when operating in a littoral environment and the need to store any accessories.

5. System Weight (weight – 4.7%)

As the USV as a limited payload allowance, the weight of the weapon selected is also an important consideration.

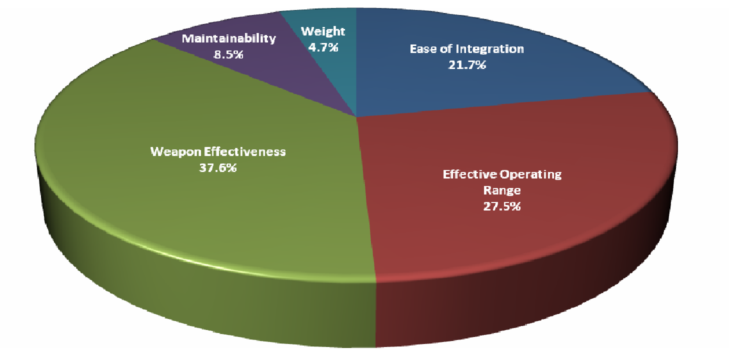

Figure 98: Criteria Weight for Non Lethal Weapon Selection

Table 53 shows the ability of the three non-lethal weapons in meeting the criteria.

Criteria	Ability to meet Criteria		
	Water Cannon	LRAD-R	MDS
Ease of Integration	High	High (currently in used by US Navy)	Medium (currently only vehicle mounted version available)
Effective Operating Range	60m	500m	35m
Weapon Effectiveness	Localized area	Whole target	Localized area
Weapon Maintainability	Low	Low	High
System Weight	250 lbs (estimated)	230 lbs	900 lbs

Table 53: Criteria for Non Lethal Weapon Selection

Based on AHP analysis, the Water Cannon System has a global weighted evaluation of 37.9%, LRAD-R of 52.3% and MDS of 9.8%. It is therefore recommended to select LRAD-R as the non-lethal weapon to be integrated onto the Spartan USV.

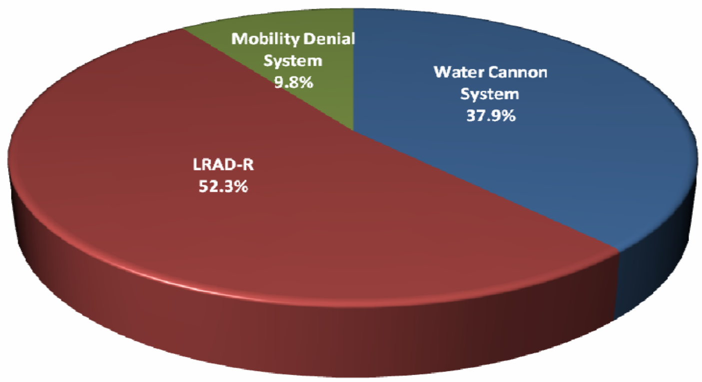

Figure 99: Global Weight for Non Lethal Weapon Selection

The output charts from AHP run are shown below.

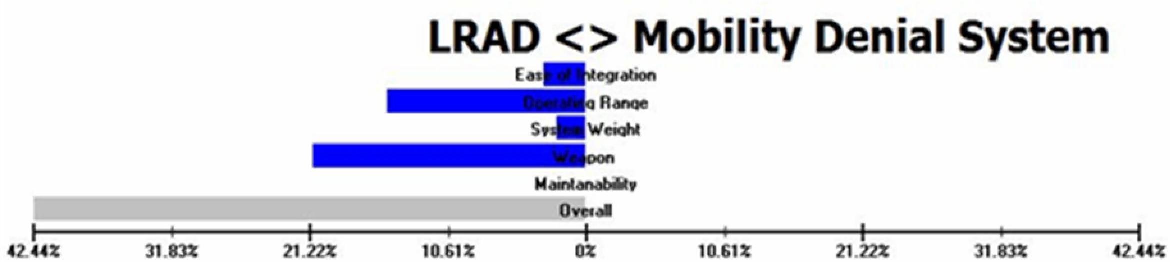

Figure 100: Head to Head Between LRAD and Mobility Denial System

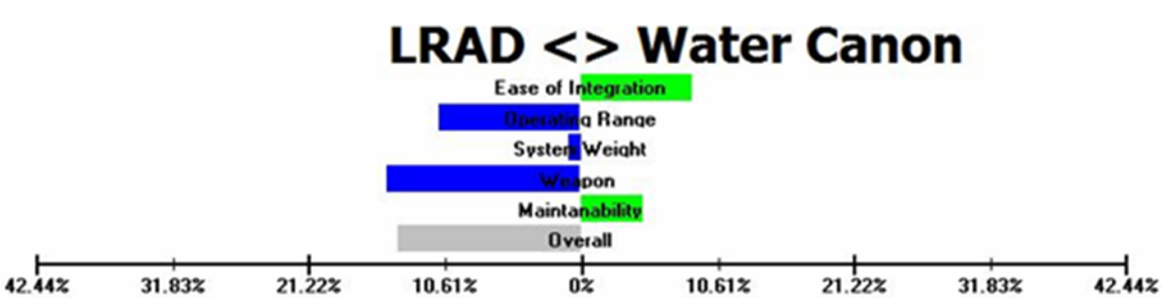

Figure 101: Head to Head Between LRAD and Water Cannon

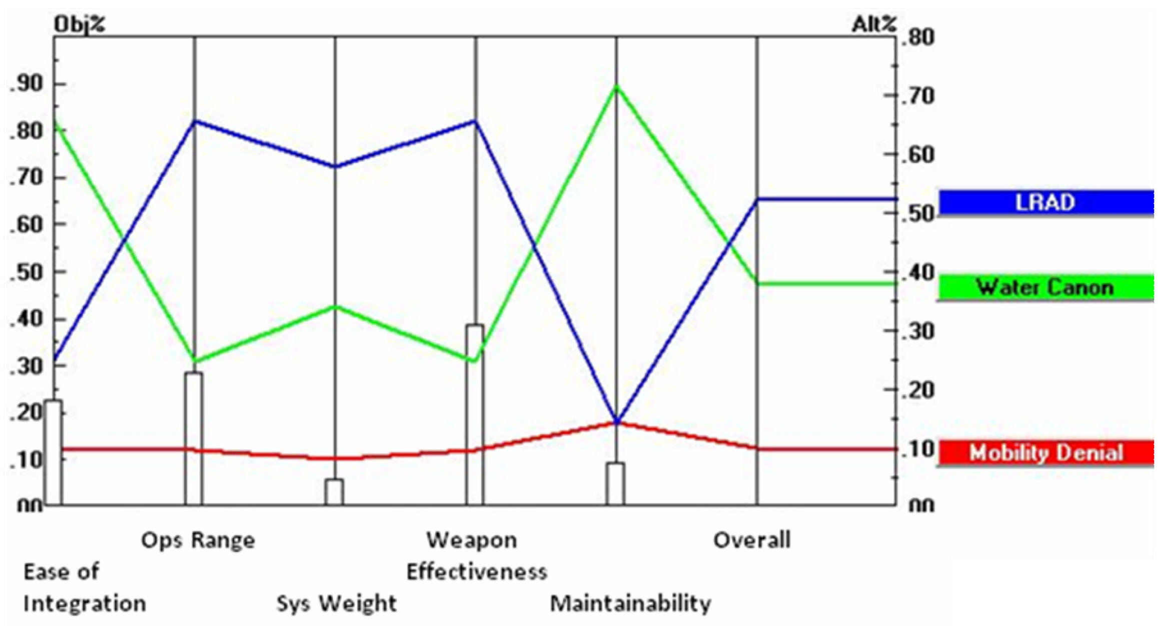

Figure 102: AHP Results for Non Lethal Weapon Selection

B. TECHNICAL SPECIFICATIONS

1. Technical Specification for High Pressure Water Cannon System

Figure 103: High Pressure Water Cannon System

Pressure:11 kPa

Weight: 200 lbs (estimated)

Effective Range: 50-60m

2. Technical Specification for Remote Long Range Acoustic Device

Figure 104: Long Range Acoustic Device

Gross Weight: 230 pounds

Dimensions: 44"W x 20"D x 49"H

Maximum SPL: 151dB instantaneous tone @ 1 meter

Beam Width: +/- 15^{o} at 2khz

Power: 600 Watts (Peak Consumption)

Source: American Technology™ Corporation product catalogue

3. Technical Specification for Anti-Traction Mobility Denial System

Figure 105: Anti-Traction Mobility Denial System

Formula: Polyacrylamide powder mixed with water to produce an extremely slippery surface.

Acts on: Concrete, asphalt, mowed grass, packed earth, and wood, tile, and vinyl floors

Capacity: 300 gallons on platform transportable system

Range: Reaches 100ft

Area Covered: 120,000 sq ft

Weight: 900 lbs

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LCDR Robert Silva
CPT Lior Harari
CPT Cher Howe Ong
CPT Kok Kiang Lee
CPT Chor Chow Seng

Intercept: MAJ Hoon Hong Teo (Crafty)
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CPT Say Beng Neo
CPT Mun Lok Soh
CPT Lee Tat Rudy Lim
Miss Ai Lin Tan, Sharon
Mr. Khim Yee Kam
Mr. Weng Heng Chua

Search: Mr. Kine Seng Tham
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Mr. Choon Wei Poh
Mr. Chun Hong Low
Mr. Pick Guan Hui

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